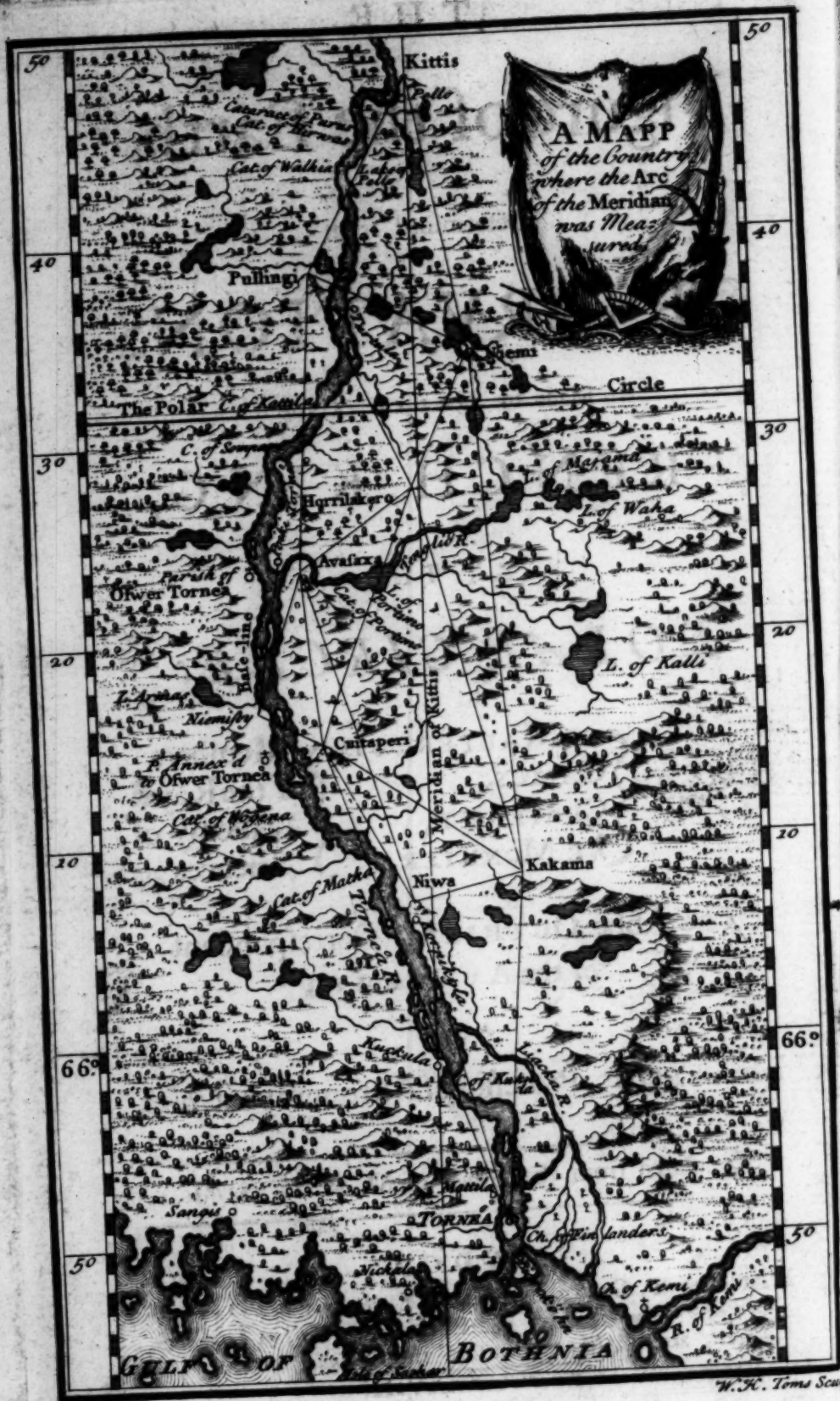


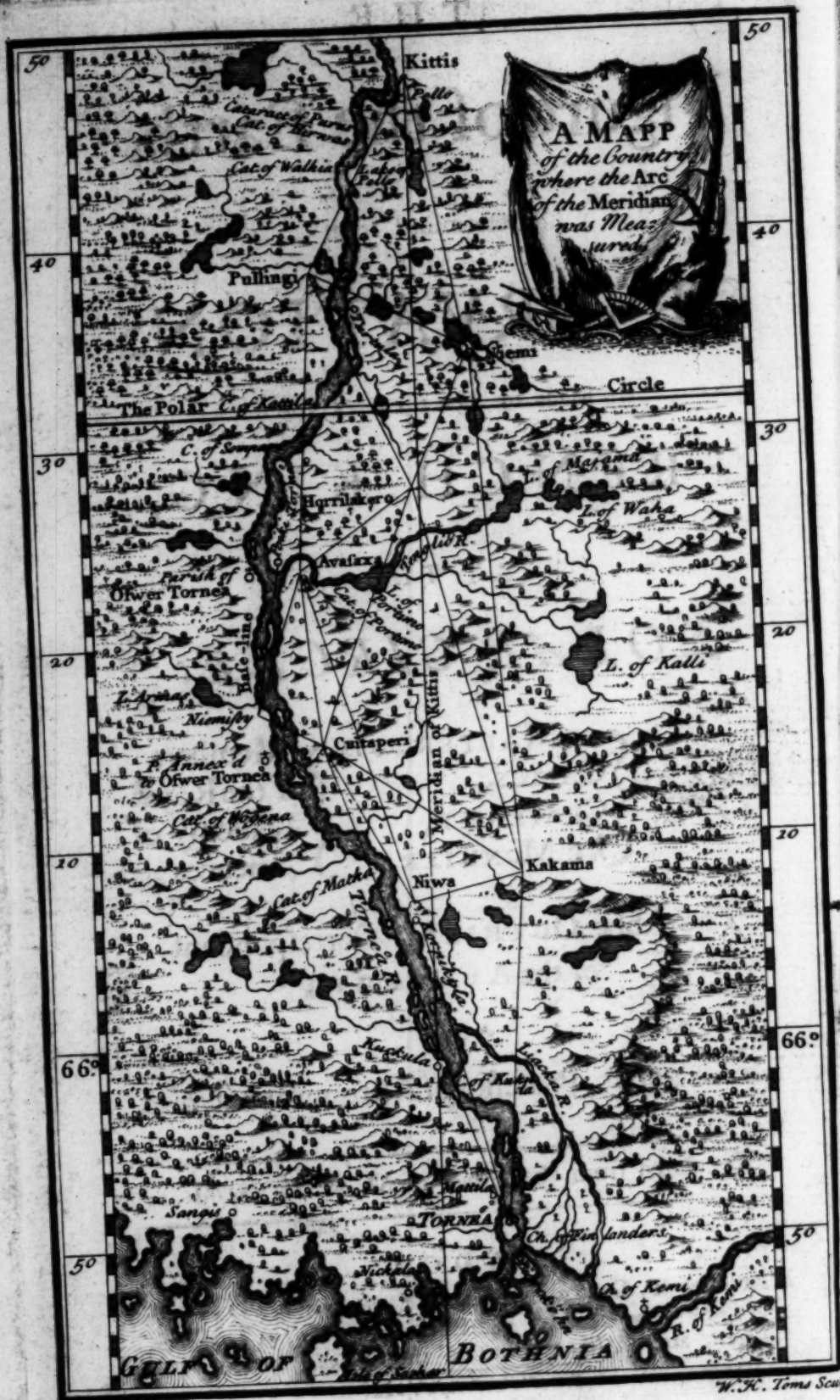


By

Mr.

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the



THE
Figure of the Earth,
Determined from
OBSERVATIONS

Made by ORDER of the
FRENCH KING,

AT THE
POLAR CIRCLE:

h Moreau
By Mess^{rs} { DE MAUPERTUIS, } Members
 { CAMUS, } of the Royal
 { CLAIRAUT, } Academy of
 { LE MONNIER, } Sciences ;

The Abbé OUTHIER, Correspondent
of the ACADEMY ;

AND

Mr. CELSIUS, Professor of Astronomy at *Upsal*.

Translated from the *French* of M. de Maupertuis.

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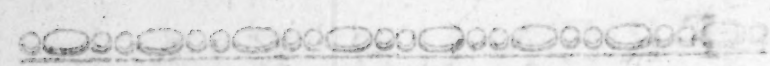
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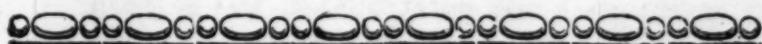
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Read in the Publick Meeting of the Royal Academy
the 15th of April, N. S. 1738.



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The AUTHOR'S
PREFACE.

THE great Attention of the Public to what shall be decided in the Question concerning the Figure of the Earth, has not permitted me to delay printing this Treatise till it should appear in the course of our annual *Memoirs*. As I intend to place the Whole of our Operation in the clearest Light that's possible, that every one may judge of its Accuracy, I have set down the Observations themselves, just as they stood in the Registers of Messrs. *Clairaut, Camus, le Monnier, Outhier,*

B

tbier, and my own, which all agreed with each other; without making the *Corrections* usual in Works of this nature. Whose Authors, suppressing their Observations, have thought it sufficient to give the Triangles *corrected*, and their Angles *reduced* to the just Sum of 180 Degrees; with the *Mean* of their Observations of the Amplitude of the Arc they measured. But the Method I have used will, I conceive, be the most satisfying to my Readers; as it enables them, from the Agreement or Differences of the Observations, to see how far they reach or fall short of the Accuracy required. They may too, if they please, make Calculations of their own in a different Manner, and compare the Result with ours.

HERE

HERE it may not be improper to say something of the Usefulness of this Undertaking ; which includes likewise the Voyage to *Peru*, begun before ours, and not yet finished.

IT is well known of what different Opinions the Learned have been these 50 Years past, with relation to the Figure of the Earth ; some holding it to be that of a *Spheroid* flatted towards the Poles ; others that it is a Spheroid prominent in that Direction. This Question, for its Curiosity only, might well merit the Consideration of Philosophers and Mathematicians : But the Advantages arising from the Discovery of the Earth's true Figure, go beyond mere Speculation ; they are real, and of very great Importance.

WERE the Position of Places with respect to Longitude and Latitude ever so exactly marked on our Globes and Charts, it would signify little to the finding their true Distances, while we were ignorant of the length of the Degrees of the *Meridian* and of the *Parallels* to the *Equator*. And if the distances of Places are not very well known, to what dangers must the Ships be exposed that are bound for them !

WHILE the Earth pass'd for perfectly Spherical, it was enough to find the exact Length of any one Degree of a Meridian ; this would give all the rest : And the Degrees of the *Parallels* might be deduced by an easy Computation. Princes and Philosophers had in all Ages been making Attempts this way. But the
Mea-

Measures of the Ancients were so inconsistent with one another, as to differ sometimes by more than one half. And if to this we add the Uncertainty we are in as to the exact Length of their *Stadia* and *Miles*, we shall find that what they have left us upon this Subject is very little to be depended upon. In later times, Surveys were made, free indeed of the Inconvenience last mentioned, but which served to almost as little purpose as those of the Ancients. *Fernel*, *Snellius* and *Riccioli* have severally given us the Length of a Degree of the *Meridian*; but when you compare them with each other, you will find Differences that rise to 8000 Toises *Paris* Measure; that is, to about the seventh part of a Degree. And tho' *Fernel* happened to come nearest the Truth, as

this could not be known, nor even presumed from the Method in which he went to work, his Measure was as useless as the rest.

WE must not however omit mentioning a *Survey* that was made in *England* in the Year 1635, because it appears to have been done with great Care, and with proper Instruments. Mr. *Norwood* having in two different Years taken the Sun's Altitude at the Summer Solstice at *London* and at *York*, with a Sextant of five foot Radius, found the difference of Latitude of these two Cities to be $2^{\circ} 28'$. He then measured their Distance, and having taken into the Account all the turnings of the Road, with the Ascents and Descents, reduced it to an Arc of the Meridian containing 9149 Chains. This compared with the Difference of Latitude

P R E F A C E. 7

tude gave him 3709 Chains to a Degree ; that is, 367196 feet *English*, or 57300 of our Toises.

A N Order of LOUIS XIV. to the *Academy of Sciences*, soon produced a Work far surpassing whatever had been done of this kind. M. *Picard*, upon a Base exactly measured, and by a very few Triangles, determined the Length of the Arc of the Meridian between *Malvoisine* and *Amiens* to be 78850 Toises : He observed, with a Sector of 10 foot Radius, that bore a Telescope of the same length, the difference of Latitude of these two Places, *viz.* $1^{\circ}. 22'. 55''$. And from thence concluded a Degree to contain 57060 Toises.

THE Method that Mr. *Picard* had used, with the many Precautions he had taken, were sufficient Vouchers for his exactness. And the KING resolved that the whole Arc of the Meridian through *France* should be measured in the same manner. This Work Mr. *Cassini* finished in the Year 1718. He had divided the Meridian of *France* into two Arcs, which he measured separately. The one from *Paris* to *Collioure* had given him 57097 Toises to a Degree; the other from *Paris* to *Dunkirk*, 56960; and the whole Arc from *Dunkirk* to *Collioure*, 57060; the same as Mr. *Picard*'s.

AT last Mr. *Musschenbroek*, jealous of the Glory of his Nation, to which himself so much contributes, having resolved to correct the Errors
of

P R E F A C E. 9

of *Snellius*, both from his own Observations and from *Snellius* himself, found the Degree between *Alcmaer* and *Berg-op-som* to contain 29514 Perches, 2 foot, 3 inches *Rhinland* Measure, which he says is equal to 57033 Toises, 0 feet, 8 inches of *Paris*.

THESE last Surveys agreed so much better with each other than the former, that for the Climates they were made, we needed no better; nor indeed to find the Circumference of the whole Earth, provided it were Spherical, and had all its Degrees equal.

BUT why should the Earth be a Sphere? In an Age when nothing less than the utmost Precision in all Science is insisted on, it was not to be supposed

supposed that the Proofs the Ancients had given of its spherical Form could pass. Even the Reasonings of the most celebrated Mathematicians, who gave it the Figure of a flat Spheroid, were not thought entirely satisfying; because they seemed still to be connected with some Hypotheses, although these Hypotheses were such as one cannot well help admitting. As for the Observations made in *France*, they were as little thought sufficient to give the Earth the Figure of a long Spheroid.

A T last the KING order'd the length of a Degree to be measured at the Equator and at the polar Circle, that the Comparifon of one of these Degrees with that in *France* might decide whether the Earth was long or flat; and that at the same time

P R E F A C E. II

time their Comparifon with each other might determine the Earth's Figure in the exacteft manner.

IT is evident in general, that Sir *Isaac Newton's* Figure of a flat Spheroid, and Mr. *Caffini's* of a long one, will give very different Distances of Places that have the fame Longitude and Latitude. And it is of fome confequence to Navigators, not to fancy they are failing upon one of thefe Spheroids, while they are really failing upon the other. The Miftake would not be fo confiderable, if the Ship's Courfe lay all in the fame Meridian. But for Places under the fame Parallel, the difference of the Distances upon the one or the other Figure would be very great. In a Courfe of 100 Degrees Longitude, there might be a Miftake of more than

than two Degrees, if sailing really upon Sir *Isaac Newton's* Earth, one should imagine himself to be upon Mr. *Cassini's*. And how many Ships have perished by smaller Mistakes ?

T H E R E is this Consideration further ; That, till the Figure of the Earth is determined, there is no knowing how far these Errors may go. And in fact it appears from our Measures that such a Mistake will be still greater than, from Sir *Isaac's* Table, it could be known to be.

I say nothing of the Mistakes that must happen in oblique Courses. It is needless to make any Estimate of them at present : Only it is plain enough that they would be so much the greater as the Course approached to a Parallelism with the Equator.

T H E

THE Errors just now mentioned merit certainly our serious Attention: And if the Sailors are not at present sensible how advantageous it would be for them to know the true Figure of the Earth, it is owing rather to the Imperfection than to the Perfection of their Art. They are subject to a great many other Mistakes in the Direction of their Course, their Distance run, and the like; amidst which the Error arising from their Ignorance of the Earth's Figure lies confounded and hid. Yet it is still a Source of Error more: And if ever (as it is to be hoped) the other Elements of Navigation are brought to Perfection, it will be seen of what Use the exact Determination of the Earth's Figure is.

THIS

THIS Determination would likewise be exceedingly useful in that important Problem, *To find the Parallax of the Moon* ; which would greatly contribute to the compleating a Theory of this Satellite of our Earth ; upon which the best Astronomers have always most reckoned for the discovery of the Longitudes at Sea.

AND to come to other Objects, lower indeed, but not the less useful, one may affirm that the Perfection of *Levelling* depends upon the Knowledge of the Earth's Figure. Such is the Chain that connects the Sciences, that the same Principles which serve to direct a Ship in her Course, and to trace the Moon in her Orbit, serve likewise to bring Water into a Fountain or Canal.

'T WAS,

'T W A S, no doubt, upon these Considerations that the K I N G order'd the two Voyages to *Peru* and to the *Polar Circle*. Near Views of particular Advantage have sometimes produced great Enterprizes for the discovery of Countries, or of Passages to abridge certain Voyages; but the Determination of the Figure of the Earth is a general Benefit to all Nations and Ages.

T H E Magnificence of every thing that regarded this Enterprize was equal to the Greatness of the Design. To the four Academicians, the Count de *Maurepas* added the Abbé *Outhier*, whose Capacity to assist in this Work was well known; He gave us Mr. *de Sommereux* for our Secretary, and Mr. *d'Herbelot*
for

for *Designer*. If so many Hands were necessary for executing a Work of such difficulty and in such a Country, our Number would at the same time render our Operations the more authentic. And that nothing might be wanting in either of these respects, the KING consented that M. *Celsius*, Professor of Astronomy at *Upsal*, should join us. Thus we left *France*, furnished with all that could be thought necessary to ensure Success; and the Court of *Sweden* gave such Orders, as procured us in its remotest Provinces all the Assistance imaginable. The Count of *Casteia* then Ambassador in *Sweden*, solicited the Recommendations of that Court, with that Zeal he always shows in the KING's Service; and if we have done any thing for the Sciences, that deserves Acknowledgment, they will pay

pay it to that Minister, to whose goodness we are so much indebted,

I thought it might not be disagreeable to my Readers to prefix a short History of our Labours, which was read in the last publick Meeting of the Academy ; and of which I have retrenched only some Reflections, that the detail of our Operations has now render'd superfluous.

THE rest of the Work is divided into three Books ; because it treats of very different Matters.

IN the first you have the whole Process of our Operations for measuring an Arc of the Meridian that cuts the Polar Circle, and for assuring ourselves that our Measures were just. It is divided into two Parts,

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the one containing our first Operations ; the second the Repetition of these Operations, with Verifications of the Whole.

OUR scrupulous Exactness not only in the Calculations, but in the detail of all the Circumstances of our Observations, may to some People seem to need an Apology. But in a Subject that has been so much disputed, and is of such importance, we thought we could not carry our Exactness too great a length. Mr. *Clairaut*, whose Skill in much more difficult Calculations is well known, was of great service to us in these.

THE first Book concludes with a Problem which I had already published in the *Memoirs of the Academy* 1735, and which I have here inserted,

serted, because this is its proper place. It serves to determine the Magnitude and Figure of the Earth from the lengths of two Degrees of a Meridian; and by it, one may easily make a Table of the lengths of a Degree for every Latitude.

THE second Book contains several Observations by which we determined the Elevation of the Pole at *Torneå* and *Kittis*; the quantity of the Refraction at the Polar Circle, and the Longitude of *Torneå*. We at the same time detect a received Error, which might not a little affect both Astronomy and Geography.

IN the Year 1695 *Charles XI.* King of *Sweden*, having sent Mess^{rs}. *Spole* and *Bilberg* to *Torneå* to make some Astronomical Observations;

these two Mathematicians, with small and imperfect Instruments, observed several Altitudes of the Sun at the Summer Solstice, from which they concluded the Elevation of the Pole at *Torneå* to be $65^{\circ}.43'$; while if they had employed the proper *Data* they should have found it to be but $65^{\circ}.40'$. even by their own Observations. Having thus determined the Elevation of the Pole, their Observations of the Sun's North Meridian Altitude gave them the Refractions at *Torneå* almost double to what they are in *France*.

IN all this there was a great deal of Error: The Town of *Torneå* is $11'$ more to the North than they made it; And the Refractions are not there different from what they are at *Paris*.

FROM

P R E F A C E. 21

FROM a great Number of Observations we found the Elevation of the Pole at *Torneå* to be $65^{\circ}. 50'. 50''$. And we have some reason to think there are few Towns in the most inhabited parts of *Europe*, whose Latitude is more exactly known. We have there oftner than once observed, at short intervals of Time, and even in the same Day, the two Altitudes of the Pole-Star, which is there so elevated, that though one knew not the Refractions, or made no account of them, they are so inconsiderable that the observed Altitude might afterwards be safely used in measuring the Horizontal Refractions.

ON the other hand, in this Climate the Sun's Meridian Altitudes

in the Horizon furnish many curious Observations upon the Subject of Refraction.

WE had likewise the Planet *Venus* for about two Months constantly above the Horizon, and could take her Meridian Altitudes both to the South and North.

AND from all these Observations made with the greatest Care, we found that the Refraction at *Torneå* differed not from that in *France*: any difference we found was no more than what might arise from the Observations themselves, or from Accidents wherewith the Refractions upon the Horizon may be affected.

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IF then the Refractions are found to be considerably less at the Equator than at *Paris*, and that they really increase from the Equator towards the Pole: This at least is certain, that from *Paris* to the Polar Circle that Increase is imperceptible. And the Account which the *Hollanders* that wintered in *Nova Zembla* give of the Sun's appearing much sooner upon the Horizon than he ought to have done in that Latitude, cannot shake what we had confirmed to us by so great a Number of Observations.

AS to the Longitude, *Jupiter's* Situation in the Southern Signs kept him always hid in the Horizontal Vapours, at the times when we might have observed him. But we made

some other Observations to this purpose. One was of a Lunar Eclipse in the Horizon ; the rest of Occultations of fix'd Stars by the Moon ; from which we concluded with tolerable Certainty, that the difference between the Meridians of *Paris* and *Torneå* is $1^h. 23'$.

THESE Observations are chiefly owing to the Vigilance of Mr. *le Monnier* and Mr. *Celsius* ; who in a Climate, where the Heavens are so coy to Observation, were continually attentive to seize every favourable Moment.

THE last Book contains our Experiments upon the Force of Gravitation in the Frigid Zone : A Subject which, besides its general Importance

tance in Natural Philosophy, is so closely connected with the Figure of the Earth, that Sir *Isaac Newton* and Mr. *Huygens* thought, that from the different Weight of Bodies alone the Earth's Figure might be determined, and even more exactly than by an actual Mensuration of the Degrees. Upon the discovery of the Increase of Gravitation towards the Poles, they concluded, that to preserve the ballance of the Parts that compose this Globe, and that the Seas might not overflow the Parts towards the Equator, the Earth must there rise higher, and fall in towards the Poles. From the Increase of Gravitation as we found it at the Polar Circle, this Falling in must be still greater than Sir *Isaac* has made it. And some Experiments of our Academicians at the

the Equator, which are lately come to our hands, confirm the same Thing.

I conclude the Whole with a Problem ; To find the Direction of the primitive Gravity, or the Angles it makes with that of actual Gravitation ; which was the more proper in this place, as it comprehends the Result of all our Observations, both for the actual Mensuration of the Earth, and upon the Increase of Gravitation, and as from it may be deduced particular Solutions of a great many curious and useful Questions upon these two Subjects ; which are necessarily complicated with each other.

I have added a Map of all our Mountains and the Country adjoining ; but the Position of those Mountains only on which we made our Observations, is determined geometrically.



I have added a map of the
the United States and the
the United States and the
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15 COURSE

15 COURSE MEETING

The course is designed for
the student who has completed
the first course in the
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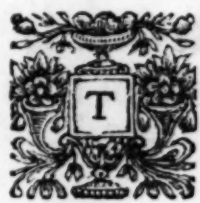


A
DISCOURSE
READ IN THE
PUBLICK MEETING
OF THE

Royal Academy of SCIENCES,

The 13th of November, N. S. 1737,

*Upon the Measure of a Degree of the
Meridian at the Polar Circle.*



THE Motives and Purpose of our Journey to the North, I laid before this Assembly eighteen months ago : at present I am to give an account of its Execution, which it may not be improper to introduce by shortly resuming what first gave rise to this Undertaking.

IN

30 *A Degree of the Meridian*

IN the Year 1672, M. *Richer* having observed, that at the Island of *Cayenne*, in the Neighbourhood of the Equator, Bodies weighed less than in *France*; this Discovery, with the several Consequences that must follow from it, drew the attention of the Learned; and an illustrious Member of this Academy found that it equally proved the Motion of the Earth round its Axis, which did not much want any new Proof, and the Falling in of the Earth towards the Poles, which was then a Paradox. M. *Huygens* applying his new invented Theory of Centrifugal Forces to the Parts that compose the Terrestrial Globe, shewed, that if we consider these parts as gravitating uniformly towards a Centre, and at the same time, revolving round an Axis, they must, to preserve their mutual Ballance, take the Form of a *Spheroid flattened* towards the Poles. He went so far as even to determine the quantity of this *Flatness*; and all this from the common Principles of Gravitation.

SIR *Isaac Newton* setting out from a different Theory, that of the universal Attraction of Matter, arrived however at the same
Con-

measured at the Polar Circle. 31

Conclusion with M. *Huygens* ; only the quantity of this *Flatness* came out different in Sir *Isaac*'s Calculation. In short, one may venture to say, that if we examine the Figure of the Earth by the Laws of *Statics*, all the different Theories lead to the same Conclusion ; whereas the Figure of an *oblong* or *oval Spheroid* cannot result but from *Hypotheses* of *Gravitation* that are extremely forced and unnatural. ?

UPON the Establishment of the *Academy of Sciences*, one of their first Researches had been, the just measure of a degree of the Terrestrial Meridian. And this M. *Picard* had executed, for the Climate of *Paris*, with all the Exactness that could be desired. But this Measure could be universally true, only upon the Supposition of the Earth's being perfectly spherical. If it was a flat Spheroid, it must be too great for the Degrees towards the Equator, and too little for those towards the Pole. ?

THE whole Arc of the Meridian that passes through *France* was afterwards actually measured. But to our great surprize, the

32. *A Degree of the Meridian*

the Degrees to the Northward came out shorter than the more Southerly, quite the reverse of what was to be expected from the Figure assigned by Messrs. *Huygens* and *Newton*. According to this last Survey, the Earth must be prominent towards the Poles ; and other Operations made upon the *Parallel* that passes through *France*, which seemed to be of great weight, confirmed the same thing.

THUS was the Academy divided in their Sentiments, and perplexed even by their own Enquiries, when the KING thought fit to signify his pleasure, that the Question should be finally decided. A Question not vainly speculative, and fit only to exercise the idle and fruitless Subtilty of Philosophers, but which might have a real influence upon *Astronomy* and *Navigation*.

TO give a proper Solution, it was necessary to compare two degrees of the Meridian, the most different in Latitude that was possible. For if these degrees increase or decrease from the Equator to the Pole, the small difference between two neighbouring degrees, might mix itself with the Errors

com₂

committed in *Observing*: whereas if the degrees that are compared, lie at a greater distance from each other, this difference being repeated as often as there are intermediate degrees, must rise to a Sum too considerable to escape Observation.

THE *Count de Maurepas*, a Lover and Patron of Learning, and who aims always at rendring it subservient to the Good of the State, found the advantage of *Navigation* and that of the *Academy* equally concerned in this Undertaking. And the same view of publick Utility engaged the attention of the Cardinal *de Fleury*, whose Protection and Favour the Sciences enjoyed in the midst of a War, in a higher degree than they durst have hoped for in the most profound Peace. To the great joy of the Academy, an Order is presently dispatched from Court to determine the Controversy concerning the Figure of the Earth; and, a certain number of its Members are immediately deputed to put it in execution.—So many were to go to measure the first Degree of the Meridian at the Equator; These set out a whole Year before us. The rest were commissioned Northward, to

D measure

34 *A Degree of the Meridian*

measure the remotest Degree they could reach. And the same Alacrity, the same Zeal to serve their Country appeared in those that were to endure the Rage of Equator Suns, and those that were to freeze beneath the Polar Circle.

THE Company destined for the North was composed of four Academicians, Mess^{rs} *Clairaut, Camus, le Monnier, and Myself*; the *Abbé Outhier*, and M. *Celsius* the celebrated Professor of Astronomy at *Upsal*, who assisted at all our Operations, and whose Abilities and Advice were of singular use to us. If I might be allowed to do justice to the Courage and Talents of the rest of my Companions, it would appear that the Work we were engaged in, difficult as it was, must become easy in such Company and with such Assistance.

26. ? THE Gentlemen that failed for the Equator we have no accounts of this great while past. Scarcely know we any thing more of them, than the difficulties they have had to struggle with: and our own Experience has taught us to fear the worst. For us, we have been more fortunate; and are safe

returned to present to the *Academy* the fruit of our Labours.

N O sooner was the Vessel that carried us over arrived at *Stockholm*, than we resolved without loss of time to set out for the Bottom of the Gulph of *Bothnia*, where we might judge which side of the Gulph was the most proper for our Operations, better than we could do by trusting to our *Charts*. Nothing could retard us, neither the frightful Stories they told us at *Stockholm*, nor the Goodness of his *Swedish Majesty*; who, notwithstanding the Orders he had given in our behalf, told us oftner than once, that it was not without a sensible Concern he saw us pursue so desperate an Undertaking. We arrived at *Torneå* time enough to see the Sun perform his Course for several days together without setting: a Sight that strikes with wonder an Inhabitant of the Temperate Zones, even though he knows it is what must necessarily happen in that Climate.

HERE it may not be amiss to give some Idea of our intended Work, and the Operations we had to go through, to measure a Degree of the Meridian.

36 *A Degree of the Meridian*

EVERY body knows that as one advances towards the North, the Stars about the Equator appear lower, and those towards the Pole more elevated. And 'tis probably this Appearance that gave the first Indication of the Earth's Roundness. This difference of the Altitudes of the same Star seen from the Extremities of an Arc of the Terrestrial Meridian, I call the *Amplitude* of that Arc. This *Amplitude* is the Measure of the Curvature of the Arc; or, as it is commonly exprest, it is the number of Minutes and Seconds that Arc contains.

IF the Earth was perfectly spherical, the Amplitude, or difference of the Meridional Altitudes of the same Star, would be always proportional to the length of its correspondent Arc in the Terrestrial Meridian. Thus, if, in the Climate of *Paris*, a distance of 57000 Toises upon the Terrestrial Meridian answered to an *Amplitude* of one degree, at *Torneâ*, to produce the same difference of Meridional Altitude, an equal distance of 57000 Toises must be gone over in the Meridian.

IF

IF, on the contrary, the Surface of the Earth was a perfect Plane, how far soever one travelled Northward, the Meridional Altitudes of the Stars would suffer no change.

IF therefore the Surface of the Earth has, in different Climates, different degrees of Curvature; that is, if it approaches more or less to a perfect Plane, the Portions of the Terrestrial Meridian, that, in different Climates, answer to the same Amplitude, must be of different Lengths. If the Earth is flattened towards the Poles, a Degree of the Terrestrial Meridian will be longer towards the Poles than towards the Equator. And by the comparison of distant Portions of the Terrestrial Meridian that answer to a Degree, the Figure of the Earth may be determined.

HENCE it is clear, that to find the Length of a degree of the Terrestrial Meridian, a certain Distance must be actually measured upon it, and the different Altitudes of the same Star must be taken at the two Extremities of that Distance, in order to compare the Length of the Arc with its Amplitude.

OUR first Work then was to measure some considerable Distance in the Meridian; and for that purpose to form a Series of Triangles connected with a Base, whose Length we could take by an actual Survey.

WE had all along flattered ourselves that we might perform our Operations upon the Coasts of the Gulph of *Bothnia*. The convenience of transporting ourselves and our Instruments to the different Stations, by Sea, with the many advantageous Points of View which the Islands, as they are marked in all the Charts, seemed to promise us, had turned our Thoughts altogether upon these Coasts and Islands. But when we had gone with great impatience to view them, all our labour served only to convince us, that our first Design was impracticable. These Islands, which line the Coasts of the Gulph, and the Coasts themselves, which we had fancied to be so many Promontories, that might furnish us with distant Points of View from one to another, lay all of them so low upon the Surface of the Water, that at a small distance, the Convexity of the Earth must arise between them and us. Near the Coast they
even

even covered one another from our sight : Nor did they advance far enough into the Sea to afford us the Direction we wanted. So that after several small Voyages in pursuance of our first Design of making use of these Islands, we were at last obliged to give it up.

I had set out from *Stockholm* to *Torneå* in a Coach, with the rest of the Company : but about the middle of this long Journey, having accidentally fallen in with the Vessel that carried our Instruments and Servants, I had gone on board and was got to *Torneå*, some days before my Companions. At my landing, I had found the Governour of the Province just setting out to visit North *Lapland*, which was of his Department ; and had seized the occasion of his Company, to get some notion of the Country till my Friends should come up. I had advanced 15 Leagues to the North, passed the Night of the Solstice upon *Avasaxa*, one of the highest Mountains in the Country, and had got back to *Torneå* by the time my Companions arrived. In this Excursion, which took up three Days, I had observed that the River of *Torneå*, as far as I had traced it, followed

40 *A Degree of the Meridian*

pretty nearly the Direction of the Meridian, and that there were high Mountains on every side that might furnish very distant Points of View.

HENCE we took the hint of performing our Operations upon the tops of these Mountains, to the Northward of *Torneå*; but the thing appeared next to impossible.

IN the Desarts of a Country scarcely habitable, in that immense Forest which extends from *Torneå* to *Cape Nord*, we must go through Operations that are not easy even where no Convenience is wanting. To penetrate into these Desarts, there were but two ways, both of which we must prove; one, the sailing upon a River full of Cataracts; the other, crossing thick Woods and deep Marshes on foot. And if we should be able to make our way into the Country, after the most painful Marches, we must have to clamber up steep Rocks, and clear the tops of Mountains of the Wood that intercepted our Sight. We must in these Desarts put up with the most wretched Diet, exposed to the Flies, which in this Season are so insufferable as to drive the *Laplanders* and

and their Rain-Deer from their Habitations to seek shelter on the Coasts of the Ocean. In fine, we must undertake this Work without knowing, or being able to inform our selves, whether it was at all practicable; whether the want of one Mountain might not, after all our Toils, absolutely interrupt the Series of our Triangles; or whether it would be possible to find upon the River, a *Base* with which they could be connected. If none of these Obstacles proved insurmountable, still there remained the Labour of building *Observatories* upon the most Northerly of the Mountains, the carrying thither as numerous a Collection of Instruments as is perhaps to be seen in *Europe*, and there making the nicest Observations of Astronomy.

THESE were Obstacles sufficient to alarm us; yet on the other hand our Views were too charming to be parted with. Besides the Pleasure of conquering so many Difficulties, we should have surveyed a Portion of the Earth, the remotest that is perhaps within the reach of Mortals; the Degree of the Meridian that cuts the *Polar Circle*, and lies partly within the *frozen Zone*.
Then,

42 *A Degree of the Meridian*

Then, as we had despaired of making any use of the Islands in the Gulph, this was really the only Ressource that remained. For to go down again to the more Southerly Provinces of *Sweden*, was a Thought we could not bear.

July, WE set out then from *Torneå* on Friday
1736. the 6th of July, with a Company of *Finland* Soldiers, and a good number of Boats laden with Instruments, and such Provisions as were thought most necessary.

WE began our Journey by sailing up the great River, that rising in the inmost Parts of *Lapland*, pursues its course till it falls into the Gulph of *Bothnia*, having first divided itself into two Branches that form the Isle of *Swentzar*, where is built a Town of the same Name in the Latitude of $65^{\circ} 51'$. From this day forward, our only Habitation was the Desarts, and the Summits of those Mountains which we were to connect by our Triangles.

AFTER a Voyage of twelve hours, we landed about Nine in the Evening at *Korpi-kyla*, a Hamlet by the River-side, inhabited by

measured at the Polar Circle. 43

by *Finlanders*. And having travelled across *July*. the Forest on foot for some time, we arrived at the Bottom of a steep Mountain called *Niwa*, whose Summit, a bare Rock, we chose for our first Station. Upon the River we had been tormented by great Flies with green Heads, that fetch blood wherever they fix. But on the top of *Niwa* we had to deal with several other kinds still more intolerable. By good luck we found two *Lapland* Girls tending a small Herd of Rain-Deer, but almost quite hid in the Smoke of a great Fire they had kindled: And upon enquiry being told it was in this manner they defended themselves from the Flies, we immediately had recourse to the same Method.

THE 8th of *July*, at One in the Morning, Mr. *Camus* and I left our Company upon *Niwa*, to go and reconnoitre the Mountains to the Northward. We travelled up the River, to a high Mountain called *Avasaxa*, where having cleared its top of the Trees, we order'd a *Signal* to be built. Our Signals were hollow Cones, composed of a great many large Trees stript of the Bark. By this means they were white enough to
be

44 *A Degree of the Meridian*

July. be visible at the distance of 10 or 12 Leagues. And we had taken the precaution to cut Marks upon the Rocks, and drive Stakes into the Ground, covering them with large Stones, that, in case of any Accident, we could easily recover the Centre of our Cone. In short, our Signals were as convenient for Observation, and as solid as most Edifices in the Country.

As soon as this was finished, we came down from *Avafaxa*, and embarking on the little River of *Tengliö*, which falls into the great River at the foot of this Mountain, we directed our Course upwards to a place the nearest we could find to a Mountain that seemed to suit our purpose. And from thence a March of three Hours over a Morass, brought us to the foot of *Horrilakero*. Though extremely fatigued, we got to the top of it, and passed the Night in cutting down the Wood that covered it. Most part of this Mountain is a reddish Stone, interspersed with a sort of white Crystal, of an oblong Form, and laid parallel-wise. Here the Flies, more merciless than those of *Niwa*, were not to be driven off by Smoke. We were obliged, notwithstanding the excessive
Heats,

Heats, to wrap our Heads in our *Lappmudes*, July.
(a sort of Gown made of Rain-Deer Skins)
and to cover us over with Branches of Firr,
and even whole Trees; which rather stifled
us, than defended us from these troublesome
Animals.

HAVING cut down all the Wood on
the top of *Horrilakero*, and built a Signal,
we returned by the same road, to find our
Boats that we had drawn up upon the Bank,
the People of this Country being but ill
provided of Cordage to secure them in the
ordinary way. 'Tis indeed no hard matter
to drag along, or even carry the Vessels that
are used in the Rivers of *Lapland*. A few
thin Firr-boards compose the whole Vessel,
so extremely light and flexible, that the
continual beating, with all the force of the
Stream, against the Stones which these Ri-
vers are full of, does it no manner of harm.
'Tis terrible to those that are not accustom-
ed to it, and astonishing even to those that
are, to see one of these weak Machines
drive down a Cataract, in a Torrent of
Foam and Stones, sometimes raised aloft in
the Air, and next moment lost in the Deep.
A bold *Finlander* steers it with a long Oar,
while

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July. while his two Companions row hard to save it from the pursuing Wave that threatens every moment to overwhelm it. Then may you see the whole Keel by turns raised above Water, and leaning only with its one Extremity on the top of a yielding Billow. As these *Finlanders* have so much Courage and Address in passing the Cataracts, their Art and Care in the management of their Boats upon other Occasions is no less remarkable. A Tree, Branches and all, serves them ordinarily for both Sail and Mast.

WE embarked again on the *Tengliö*, which brought us down into the River of *Torneå* on our return to *Korpikyla*. Four Leagues from *Avasaxa* we left our Boats, and after an hour's march over the Forest, gained the foot of *Cuitaperi*, a steep Mountain, its Summit a Rock covered with Moss, and affording an extensive Prospect all round ; which, to the South, takes in the Gulph of *Bothnia* : Here we erected a Signal, whence we could discover *Horrilakero*, *Avasaxa*, *Torneå*, *Niwa* and *Kakama* ; and then continued our Course down the River. Between *Cuitaperi* and *Korpikyla* we found some frightful Cataracts,

measured at the Polar Circle. 47

rafts, where the *Finlanders* always set their *July*. Passengers ashore. But our excessive fatigue had made it more supportable to risque passing them in the Boat, than to walk but an hundred Yards. At last, on the Evening of the 11th, we joined our Friends whom we had left on the top of *Niwa*: They had descryed our Signals, but, by reason of the continual Fogs, had not been able to make any Observations.

WHETHER it is the Sun's long Stay above the Horizon, that raises more Vapour than the Night can condense, I shall not determine. This is certain, that, during the two Months we past on these Mountains, the Sky was never clear till a northerly Wind rose to carry off the Fogs. This disposition of the Air detained us sometimes 8 or 10 Days upon one Mountain, waiting for a favourable Moment, when we might have a distinct View of the Objects we wanted to observe. Next Day after our return to *Niwa* we took some Angles, and the Day following, by the favour of a cold north Wind, we were able to finish our Observations.

THE

July. THE 14th we left *Niwa*, and while Mess^{rs} *Camus*, *le Monnier* and *Celsius*, went to *Kakama*, Mess^{rs} *Clairaut*, *Outhier* and myself, took the Road of *Cuitaperi*, whence the Abbé *Outhier* went the 16th to plant a Signal at *Pullingi*. The 18th we made our Observations, which, notwithstanding some Interruption from the Thunder and Rain, were compleated that same Evening. The 20th we set out all together, and by Midnight arrived at *Avasaxa*.

THIS Mountain is situated on the bank of the River 15 Leagues from *Torneå*. Its Ascent is difficult, lying through a Wood that reaches half way up, is then interrupted by a heap of steep slippery Rocks, and afterwards continued to the very top of the Mountain, at least before we cut down so much of it as was necessary to open our Prospect. The north-east side is a most frightful rocky Precipice, where the Falcons build their Nests. At the foot of it runs the *Tengliö*, encircling *Avasaxa* before it falls into the River of *Torneå*. From its Summit the Prospect is the most beautiful that can be imagined; to the South quite un-

measured at the Polar Circle. 49

unbounded, and discovering the course of *July.*
the River to a vast extent. Towards the
East one can trace the *Tengliö* in its passage
through several Lakes. And on the North,
at a distance of 12 or 15 Leagues, the View
is terminated by a prodigious Number of
Hills, heaped one upon another, as we use
to represent the *Chaos*, and amongst which
it might not be easy, after one had got thi-
ther, to distinguish the one he had pitch'd
upon at *Avasaxa*.

WE spent 10 Days upon this Moun-
tain, during which, Curiosity procured us
frequent Visits from the Inhabitants. They
brought us Fish and Sheep, and such bad
Fruits as their Woods produce.

BETWEEN this Mountain and *Cuita-*
heri, the River is exceeding broad, forming
a sort of Lake; which, besides its extent,
was very conveniently situated for our *Base*.
Mess^{rs} *Clairaut* and *Camus* undertook to
determine its direction, and stayed for that
purpose at *Öfwer-Torneå*, after we had fi-
nished our Observations at *Avasaxa*: While
I, with Mess^{rs} *le Monnier*, *Outhier* and *Cel-*
sus, should go up to *Pullingi*. The day
E we

50 *A Degree of the Meridian*

July. we left *Avasaxa* we crossed the *Polar Circle*; and on the Morrow, the 31st of *July*, by Three in the Morning arrived at *Turtula*, a sort of Hamlet where they were cutting their little crop of Barley and Hay. After having travelled some time in the Wood, we embarked on a Lake which brought us to the foot of *Pullingi*.

THIS is the highest of all our Mountains, and of an exceeding difficult Access; as well on account of its Steepness, as the depth of the Moss wherein we had to fix our Steps: We reached the top however at six in the Morning. Our Stay here from the 31st of *July* to the 6th of *August* was no less disagreeable than the Ascent had been painful. We had to fell a whole Wood of the largest Trees. And the Flies attacked us with such Fury, that our Soldiers of the Regiment of *Westro-Bothnia*, a Body distinguished even in *Sweden*, where there are so many brave Troops; these Men, hardened with the greatest Fatigues, were obliged to wrap up their Faces, or cover them with Tarr. These Insects poisoned our Victuals too; no sooner was a Dish served, but it was quite covered over with them, while
another

another swarm, with all the rapaciousness *July.*
of Birds of prey, was fluttering round to
carry off some pieces of a Sheep that was
a dressing for us.

THE Morrow after our arrival at *Pullingi*, *August;*
the Abbé *Outbier* went with an Officer
of the Regiment of *Westro-Bothnia*, to
whose good Offices we are very much indebted,
to build a Signal towards *Pello*; and the
4th we discovered another which the same
Gentleman had erected upon *Niemi*. Having
taken the Angles between these *Signals*,
we left *Pullingi* the 6th of *August* to go to
Pello, where, after having forced our way
up four Cataracts, we arrived the same
day.

PELLO is a Village inhabited by a
few *Finlanders*: In its Neighbourhood is
Kittis, where was one of our *Signals*; the
lowest of all our Mountains. As we were
going up we discovered a copious Spring of
pure Water, that issues from a fine gravel,
and resists the keenest Frost. For when
we returned to *Pello* about the end of Win-
ter, while the Sea at the bottom of the
Gulph, and all the Rivers were frozen as hard

52 *A Degree of the Meridian*

August. as Marble, we found this Spring running as in Summer. We had the good fortune to make our Observations soon after our arrival, so that we were obliged to stay at *Kittis* but till next day. We set out from thence at three o'clock in the Afternoon, and came the same Evening to *Turtula*.

FOR a Month past we had been Inhabitants of the Desarts, or rather of the Mountains tops; the Earth or Rocks, spread with the Skin of a Rain-Deer, had been our Beds, and our Food chiefly Fishes that the *Finlanders* brought us, or which ourselves had catch'd, with some sort of Berries or wild Fruits that grew in the Woods. This way of living did by no means agree with Mr. *le Monnier*. His Health had been sensibly upon the Decline, especially from the hardships we had suffered upon *Pullingi*, and being now quite gone, I was obliged to leave him at *Turtula* to go down the River, and try to recover it at the Curate of *Öfwer-Torneå's* House, which was the best, and almost the only place of Shelter in the Country.

I left *Turtula* at the same time in company with Mess^{rs} *Outhier* and *Celsius*, to

go across the Forest and find out the Signal *August.*
which the Officer had erected at *Niemi.*
And a frightful Journey it was. We set
out from *Turtula* on foot till we got to a
Brook, where we embarked on three little
Boats. But they passed with such difficulty
between the Stones, that we had to go out
of them at every turn, and leap from one
Rock to another. The Brook brought us
to a Lake so full of little yellowish Grains,
of the bigness of Millet, that the whole
Water was discoloured with them. I took
them to be the *Chrysalis* of some Insect, and
was tempted to fancy that this Insect must
be some kind of those Flies that so tormented
us; for I could think of no other Species
of Animals whose Numbers corresponded
to the quantity of Grains that covered this
large Body of Water. From the Extremity
of this Lake we had to walk to another
of very clear Water. Here we found a
Boat, and putting our Quadrant on board,
resolved to follow it along the side of the
Lake on foot. But the Wood was so thick,
that we were forced to cut our way through
it, and were entangled at every step by the
depth of the Moss and the fallen Fir-trees
that lay across our Road. In all these Woods

54 *A Degree of the Meridian* ...

August. there are almost as many fallen Trees as standing. The Soil, after it has reared them to a certain height, can no longer furnish the proper Nourishment, nor is it deep enough to allow them to take firm root. The least blast of Wind oversets them, and in all these Woods one sees nothing but Firrs and Birches rooted out in this manner. The wood of the latter, Time reduces to Dust without at all affecting the bark; and one is surprized to find pretty large Trees that crumble upon the slightest touch. This has probably given the hint of the use the *Swedes* make of it, to cover their Houses; and indeed there could be nothing imagined fitter for the purpose. In some Provinces they cover the Bark with Earth, which forms upon the Roof a sort of Garden, such as are to be seen upon the Houses of *Upsal*. In *Westro-Bothnia*, the Bark is bound with Firr-Poles, fixt a-top, and hanging down on either side of the Roof. Our Woods then had rather the Aspect of the Ruins of Woods whose Trees have most of them perished; And it was thro' one of these, one of the most horrid of them too, that we must pass, with the twelve Soldiers that carried our Baggage. Having at length reach'd a third
Lake

Lake very large, and the finest Water that *August.* can be imagined, we put our Instruments and Baggage on board two Boats we found there, and waited their return upon the Coast. The high Winds, and bad Condition of these Boats rendred their Passage tedious. Yet they came back at last, and ferry'd us over to the foot of *Niemi* by Three o' Clock in the Afternoon.

THE beautiful Lakes that surround this Mountain, and the many difficulties we had to overcome in getting thither, gave it the Air of an enchanted Island in a Romance. And indeed any where but in *Lapland* it would be a most delightful place. On one hand you see a grove of Trees rise from a Plain, smooth and level as the Walks of a Garden, and at such easy distances as neither to embarrass the Walks, nor the Prospect of the Lake that washes the foot of the Mountain. On the other you have Apartments of different Sizes, that seem artificially cut in the Rock, and to want only a Roof to compleat them. And the Rocks themselves so perpendicular, so high and so smooth that you would take them for the Walls of an unfinished Palace rather than for the work

56 *A Degree of the Meridian*

August. of Nature. From this height we had Occasion several times to see these Vapours rise from the Lake, which the People of the Country call *Haltios*, and which they deem to be the guardian Spirits of the Mountains. We had been frightened with Stories of Bears that haunted this place, but saw none. It seemed rather a place of resort for *Fairies* and *Genii* than for Bears.

THE Day after our Arrival, the Fog hindered our Observations. The 10th we suffered some Interruption from the Thunder and Rain, but the Day following we had them compleated, left *Niemi*, repassed our three Lakes, and were got back to *Turtula* by Nine in the Evening. We parted from *Turtula* on the 12th, and at three in the Afternoon joined our Friends at the Curate's of *Öfwer-Torneå*, where leaving Mr. *le Monnier* and the Abbé *Outhier*, I set out the 13th with Mess^{rs} *Clairaut*, *Camus* and *Celsius* for *Horrilakero*. We entred the *Tengliö* with four Boats. Its Cataracts are troublesome, rather for the little Water there is, and the great number of Stones, than for the rapidity of its Stream. As we sailed along I was surprized to see, upon the banks
of

of this River, Roses of as lively a red as any *August.* that are in our Gardens. About Nine at Night we reached *Horrilakero*, but our Observations were not finished before the 17th. The 18th we returned to *Öfwer-Torneå*, where our whole Company was now assembled.

THE most convenient place for our *Base* had been already pitched upon. Mess^{rs} *Clairaut* and *Camus*, after having carefully viewed the banks of the River, had determined its Direction, and fixed its Length by Signals raised at either Extremity.

HAVING gone up to *Avafaxa* in the Evening to take the Angles which must connect this *Base* with our *Triangles*, we saw *Horrilakero* all in flames. It is an Accident not uncommon in these Woods, where there is no living in the Summer time without Smoke, and where the Moss and Firrs are so combustibile, that a Fire once kindled will spread over some thousands of Acres. These Fires, or their Smoke, have sometimes retarded our Observations as much as the thicknes of the Air. As this burning of *Horrilakero* had been no doubt occasioned by our not taking sufficient care
to

58 *A Degree of the Meridian*

August. to extinguish our Fires, we dispatched 30 Men to cut off its Communication with the neighbouring Woods. But on the 21st, after we had finished our Observations at *Avasaxa*, *Horrilakero* was still burning; we saw it involved in a Cloud of Smoke, and the Fire that had made its way downwards was ravaging all the Forest below.

SOME of the People that were sent to *Horrilakero* having reported that our Signal was damaged by the Fire, we sent to repair it; and by the precautions above-mentioned its Centre was not hard to find.

THE 22d we went to *Poiky-Tornea* upon the banks of the River, where the Signal at the North end of the *Base* stood, to take the Angles that must connect it with the tops of the Mountains. And next Day we set out for *Niemisby*, where the South Signal had been erected, in order to make the like Observations. We lay this Night in a pleasant Meadow; whence Mr. *Camus* parted next Morning for *Pello*, to prepare some Hutts where we might lodge, and to order an Observatory to be built on *Kittis*, where we were to make our Astro-

I

nomical

nomical Observations for determining the *August*.
Amplitude of our Arc.

AFTER having made our Observation at the South end of the *Base*, we went up in the Evening to *Cuitaperi*, where our last Observation for connecting the *Base* with the Triangles was finished the 26th.

HAVING lately received the News of our *Sector* we expected from *England* being arrived at *Torneå*, we made all haste to return thither, to prepare this Instrument, and the others we were to carry to the Observatory at *Kittis*; because as the Severity of the Winter was more to be apprehended upon *Kittis* than at *Torneå*, we resolved to begin our Observations for the Amplitude of the Arc, at this end of our Meridian, before the extreme Colds should come on. While every thing was getting ready for the Voyage of *Pello*, we went up to the Spire of a Church situated in the Isle of *Swentzar* (which must not be confounded with the Church of the *Finlanders*, in the Isle of *Biörcköbn*, to the southward of *Swentzar*) and having taken the Angles which this Spire made with our Mountains, we sailed from *Torneå* the 3d
of

60 *A Degree of the Meridian*

Septem. of September, with fifteen Boats, the greatest Fleet that had ever been seen upon the River; and lay that Night at *Kuckula*.

NEXT Day we arrived at *Korpikyla*; and while the rest of the Company continued their rout to *Pello*, I set out on foot for *Kakama* with Mess^{rs} *Celsius* and *Outhier*, where we arrived at 9 o'clock at Night in the midst of a heavy Rain.

THE top of *Kakama* is all of a white Stone disposed in thin Plates, and separated by vertical Planes that cut the Meridian at right Angles; these Stones had so collected the Rain that had been falling of a long time, that, except the very points of the Rocks, there was not the least Spot that was not full of Water; and besides, it continued to rain upon us all Night long. It was not possible for us to finish our Observations before the 6th; which cost us a second Night's lodging upon this Mountain, as wet and cold as the former.

WE left our Station of *Kakama* without regret. And the continual Rains with the encumbered Passage we had to make, through

through the Wood, having obliged us to exert our utmost diligence, a five hours march brought us back to *Korpikyla*, where we rested that night, and setting out next morning, reached *Pello* on the 9th of September, where our whole Company was now once more united.

OUR several Courses, in the 63 days we had past in these Desarts had furnished us as complete a Set of Triangles as we could have wished for; and an Undertaking begun in some sort at random, without knowing if it was at all practicable, had turned out so much better than Expectation, that it looked as if the placing of these Mountains had been at our own disposal. The Mountains, with the Church of *Torneå* formed a Figure enclosed on every side, within which lay *Horrilakero* as a sort of Centre, where the several Triangles that constituted it, met. The Figure it self was an oblong Heptagon, placed in the direction of the Meridian, and happened, from a Property of Polygons, to be capable of a Verification that is singular in this sort of Operations. The Sum of the Angles of a Heptagon upon a Plane is 900 Degrees; and as ours was upon a convex Surface, the Sum of its Angles must necessarily be somewhat

62 *A Degree of the Meridian*

Septem. what greater: accordingly after having observed 16 Angles, we found it to amount to $900^{\circ}. 1'. 37''$. Near the middle of the *Heptagon* lay our *Base*, the longest that was ever used, and in the plainest Surface, seeing it was upon the Ice of the River we were to measure it. The length of our *Base* warranted the Precision of our Measures of the *Heptagon*; and its Situation in the midst of so small a number of Triangles secured us against any Error of consequence.

BESIDES, the Arc of the Meridian we were to measure was of a just length to give our Operations the greatest degree of Certainty. If there is this advantage in making use of large Arcs, that the Errors one may commit in determining the *Amplitudes* are the same, whether the Arc is great or small, and that a small Arc will be more affected by the same Error than a great one: on the other hand, the Errors in the Trigonometrical Conclusions will be so much the more considerable as the Length measured is greater, and as the number of Triangles increases. If their number is very great, and if there is no Opportunity of correcting the Work, by the help of different Bases, these last Errors may multiply each other into a Sum that shall

shall more than ballance the advantage arising from the largeness of the Arc. I had, before I left *Paris*, read a *Mémoire* upon this Subject to the *Academy*, wherein I determine the length of the Arc that gives the greatest degree of Certainty. Its quantity depends upon a Comparison of the Exactness with which the Horizontal Angles can be taken, with that with which the distance of a Star from the *Zenith* can be observed. And if my Reasonings in that Paper are applied to our Operation, it will appear that an Arc either much longer or much shorter would not so well have served our purpose.

IN taking the Angles between our Signals, we made use of a *Quadrant* of two foot *Radius*, with a *Micrometer* fitted to it, which being verified a great many times round the *Horizon*, always gave the Sum of the Angles very nearly equal to 360° . We took care to place its Centre in the Centre of our Signals. Each made his Observation, and wrote it down apart: and then we took the *Mean* of all these Observations, which indeed differed very little from one another.

UPON every Mountain we had taken care to mark the Elevation or Depression of
the

64 *A Degree of the Meridian*

Septem. the adjoining Signals ; and upon these Observations is founded the Reduction of the Angles of our Figure to the Plane of the *Horizon*.

OUR Success in this first part of our Work, where we might have met with Difficulties that it was impossible for us to get over, gave us fresh Courage for that which remained, where Labour only and Industry were required.

IN a Series of Triangles, joined to each other by Sides that are common, and whose Angles are known ; if a Side of any one of these Triangles is given, it is easy to find all the rest. We could not then fail to know exactly the distance between the Spire of the Church of *Torneå*, which terminated our Heptagon on the South, to its North Extremity at the Signal of *Kittis*, once we had measured the length of our Base.

THIS Operation might well be put off till Winter ; when we should have all the Leisure and all the Ice we could desire. So we turned our Thoughts to the other Branch
of

of our Work, the Determination of the Arc *Septem.* of the Meridian that lies between *Torneå* and *Kittis*. I have already explained wherein this Determination consisted. We had to observe by how much the same fixt Star, as it passes the Meridian, appears higher or lower at *Torneå* than at *Kittis*. Or in other words, by how much this Star, as it passes the Meridian, is nearer or farther from the Zenith of the one than of the other of these two Places. The difference between these two Heights, or these two Distances from the Zeniths, is the *Amplitude* of the Arc of the Meridian between *Kittis* and *Torneå*. The Operation is simple; it is not even necessary to know the absolute distances of the Star from the Zenith of each Place, it is sufficient if we have their Difference. Yet, with all its Simplicity, it requires the most scrupulous Exactness and Caution. For this purpose we had procured a Sector of about 9 foot Radius, like that which Mr. *Bradley* uses, and with which he made his curious Discovery of the *Aberration* of the fixt Stars. It was made at *London* under the Direction of that ingenious Artist Mr. *Graham*, a Fellow of the *Royal Society*, who had exerted himself to give it all the Advantages and all

66 *A Degree of the Meridian*

Septem. the Perfection that could be wished for. He had even taken the trouble to divide its Limb with his own hands.

IT were endless to give a particular description of every thing that is remarkable in this Instrument. The main Part is very simple; but its Size, the great number of Pieces there are for rendering it manageable, the Weight of a large Pyramid twelve foot high, that supports it; all this together made it no easy matter to raise it to the top of a Mountain of *Lapland*.

WE had built two Observatories upon *Kittis*; in the one was a Quadrant of two foot Radius, a Clock of Mr. *Graham's*, and an Instrument which we owed to the same Gentleman, consisting of a Telescope perpendicular to, and moveable about an horizontal Axis. This we placed precisely at the Center of the Signal that made the angular Point of our last Triangle. Its Use was to determine the direction of our Triangles with respect to the Meridian. The other Observatory, which was much larger, was built so near the first, that the Voice of him that counted the Pendulum's Vibrations could

measured at the Polar Circle. 67

could be distinctly heard from the one to the *Septem.* other. The Sector almost took up the whole Room. What difficulty we had in carrying up so many Instruments to the top of the Mountain, I shall not mention; it is sufficient that we carried them up. The Sector's Limb we placed exactly in the Plane of a Meridian Line which we had traced; and verified its Situation by the time of the Passage of a Star, several Altitudes of which we had taken. In short, every thing was in readiness for beginning our Observations, by the 30th of *September*; and the day following we made several upon the Star δ of the *Dragon*, all agreeing to within less than 3 Seconds.

IN the mean time, other necessary Observations were not neglected; we regulated our Clock every day by correspondent Altitudes of the Sun; and observed with the above mentioned Instrument, the Passage of the Sun in the Meridian, and the Hour when he past the Verticals of *Niemi* and *Pullingi*. By this means we determined the Position of our Heptagon, with regard to the Meridian: and taking the *Mean* of eight such Observations, none of which differed from another by a full Minute, we found the

68 *A Degree of the Meridian*

Septem. Angle which a Line joining the Signals of *Kittis* and *Pullingi* makes with the Meridian of *Kittis* to be $28^{\circ}. 51'. 52''$.

ALL these Observations were performed very successfully : but the Rains and Fogs had so retarded them, that we were like to fall into a Season of the Year that must cut off our Return to *Torneå*. Yet it was there we had to make the like Observations of the same Star : And this we wished to have done as soon as possible, lest the Motion of the Star should, in a longer interval of Time, produce some Error, in case it had any Motion to us unknown.

IT is evident that this whole Operation depending upon the difference of the Meridian-Altitudes of the same Star seen from *Kittis* and from *Torneå* ; this Star must, during the time of the Observations, either keep fixt to the same Point of the Heavens, or at least, if it does not, the Laws of its Motion must be known, that the difference of Altitude arising from its proper Motion may not be confounded with that which proceeds from the Curvature of the Arc of the Terrestrial Meridian.

ASTRO-

Septem.

ASTRONOMERS have, many ages since, observed a Motion of the fix'd Stars round the Poles of the *Ecliptic*, producing the *Precession* of the *Equinoxes*, and a Change of *Declination* in the Stars. This can be easily taken into the account in the present Case.

BUT the Stars have another Change of *Declination*, which, however lately taken notice of, we may depend upon as surely as on that other. For though Mr. *Bradley* is the original Discoverer of this Variation, yet his Accuracy, and the Instrument he uses, render his Observations equivalent to those of many Ages. He has found, that in observing any Star for a whole Year together, it is seen to describe in the Heavens a small *Ellipsis*, whose great Axis is about 40". This *Aberration* of the fixt Stars seemed at first subject to so great Varieties, that it was not till after a long Course of Observation that Mr. *Bradley* discovered the Theory upon which this Motion, or rather this Appearance depends. And if no less than the Accuracy of that Gentleman could have discovered this *Phenomenon*, no less than his Penetration

70 *A Degree of the Meridian*

Septem. could have assigned its Cause. I shall not undertake to explain his System, which may be seen to much better purpose in *Phil. Trans.* N^o. 406. I shall only add, that this change of Place in the fixt Stars seen from the Earth, proceeds from two Motions combined, that of the Rays of Light that come from the Star, and that of the Earth in its Orbit. If the Earth were fix'd, in order to look at a Star through a Telescope, the Telescope must have a certain Inclination, that a Ray of Light from the Star passing along its Axis, may reach the Eye. But if the Earth, carrying the Telescope along with it, moves with a Velocity that has any sensible Proportion to the Velocity of Light, its Inclination must now be altered, else a Ray of Light coming along its Axis cannot enter the Eye: and the different Positions of the Telescope will depend on the several Directions in which the Earth moves at different times of the Year. A Calculation founded upon these *Data*, the Velocity (and Direction) of the Earth in its Orbit, and the Velocity of the Rays of Light, which is known from other Experiments, will produce a difference of *Declination* of the fixt Stars, agreeing with Mr. *Bradley's* Observations; and thus
by

by increasing or diminishing the Star's Declination, by the Angles that result from this Calculation, we may consider it as having remained absolutely fixt during the Interval of our Observations. *Septem.*

ALTHOUGH the annual Motion of the fixt Stars agrees perfectly with this Theory, yet Mr. *Bradley* has discovered that they have still another Motion, incomparably slower than these two mentioned, and which is not sensible but at the end of several Years. In the most scrupulous Strictness, this too should be taken into the account. But our Observations lay all within so narrow a compass of time, that its effect must have been quite insensible, or at least smaller than we could hope to measure with our Instruments. I did indeed consult Mr. *Bradley*, to learn if he had any late Observations of the two Stars we made use of to determine the Amplitude of our Arc. Although he had not observed them, because they are too far from his *Zenith* for his Instrument to take them in, yet he was pleased to send me his last Discoveries upon the *Aberration*, and this new-discovered Motion of the fixt Stars: and the Correction or Equation he sent me

72 *A Degree of the Meridian*

Septem. for our *Amplitude*, in which he has had regard to the *Precession* of the *Equinoxes*, the *Aberration*, and this *new Motion*, differs not sensibly from that which we made for the *Precession* and *Aberration* only; as will appear from the detail of our *Operations*.

THOUGH then we may with sufficient certainty depend upon the *Correction* for the *Aberration*; yet for the sake of such as may scruple to admit *Mr. Bradley's Theory*, or may suspect some other undiscovered *Motion* in the fixt Stars, we wish'd that this *Correction* might be very small; and, for this purpose, that the interval between our *Observations*, at *Kittis* and at *Torneå*, might be the shortest possible.

WE had had some Ice ever since the 19th of *September*, and Snow on the 21st. Some part of the River was already froze; and this first imperfect Ice might render it impassable either to Boats or Sledges for a great while.

BY staying any longer at *Pello* we run a risque of not being able to return to *Torneå*, till the time between our *Observations* should be

be longer than we wished. We might like-
wise lose sight of our Star, by the too
near approach of the Sun in his annual
Course; in which case we must have re-
turn'd to *Kittis*, in the midst of Winter to
make new Observations upon another Star:
And to pass the Winter Nights in making
Observations upon the top of a Mountain,
was a thing not to be attempted.

Octob.

IF we set out presently, we were in
danger of being stopt by the Ice with all
our Instruments, we knew not where, nor
for how long time. Thus too our Obser-
vations upon *Kittis* might be rendered of
no use; a Loss which it must have been
very difficult to retrieve in this Country,
where all Summer long we could not pre-
tend to observe any Star within the reach
of our Instrument, on account of their
smallness, and their being hid by continual
Day-light: And where the Severity of the
Winter rendered Observations upon *Kittis*
impracticable.

HAVING carefully weighed all the
difficulties on either side, we resolv'd to
venture on the Journey. Mess^{rs} *Camus* and
Celsius

74 *A Degree of the Meridian*

Octob. Celsus set out with the Sector the 23d. Mess^{rs} Clairaut and le Monnier followed next Day. And the Abbé Outhier and I on the 26th. And by a singular good Fortune landed safe at Torneâ on the 28th of *October*; the People of the Country assuring us they had scarce ever known the River navigable at that time of the Year.

OUR Observatory at Torneâ being already prepared for receiving the Sector, we fixed it in the Plane of the Meridian. The first of *November* it began to freeze harder, and on the morrow the River was quite shut up. The Ice, which thawed no more, was presently covered over with Snow. And this vast body of Water, but a few days before full of Swans and other Water-Fowls, was now one immense Plain of Ice and Snow.

Novem. ON the 1st of *November* we began to observe the same Star we had observed at *Kittis*; and with the same precautions and success, the greatest differences of our Observations amounting but to one Second. In all which Observations, a faint Day-light had served to illuminate the Threads of the
Micro-

measured at the Polar Circle. 75

Micrometer. And taking the Mean of all *Novem.* our Observations, the Parts of the *Micro-meter* being reduced to Seconds, and due regard had to the Change of Declination caused by the Precession of the Equinoxes and other Motions of the Star, our *Amplitude* came out to be $57'. 27''$.

OUR Work was now in a manner completed. It was really determined whether the Earth was *flat* or *prominent* towards the Poles, without our knowing, however, on which side of the Question the Determination fell, because we had not yet measured our *Base*. This was an Operation in itself quite simple and easy, being no more than surveying the distance between the two Signals we had erected last Summer; but then this Survey was to be made upon the Ice of a River in *Lapland*, in a Country where the Cold was growing every day more insupportable; and the distance itself more than three Leagues.

WE were advised to put off this Survey *Decem.* till the Spring; because the Days should then be longer, and besides, the first melt-ings of the Snow, which are immediately
I froze

76 *A Degree of the Meridian*

Decem. froze again, would turn its Surface into a Crust strong enough to bear us; whereas, in the heart of Winter the Snows are commonly in the form of a small dry Dust, four or five foot deep, which it is impossible to pass over. But the Apprehensions of being surprized by a Thaw, however ill founded they may appear in the midst of a Frost that was growing keener every day, overballanced all other Considerations. What if we should come too late, said we, in the Month of *May*, and thus be entirely disappointed in our Design.

IN the mean time, as we did not know whether the Snow upon the River might not be already too deep, Mess^{rs} *Clairaut*, *Outbier* and *Celsius*, went on the 10th of *December* to view it. They found its depth considerable, yet not such as to make us despair of measuring our Line; so we went all together to *Öfwer-Torneå*.

Mr. *Camus*, assisted by the Abbé *Outbier*, employed the 19th and 20th in adjusting eight Rods, each 30 foot long, by means of an Iron Toise we had brought from *France*, which during this Operation we kept in

measured at the Polar Circle. 77

a place where Mr. *de Reaumur's* Thermo- Decem.
meter stood at 15 Degrees below 0, and
that of Mr. *Prins* at 62; the Degree of
Heat at *Paris* in *April* and *May*. Our
Rods once adjusted, were in no danger of
suffering any Alteration in their length from
the Cold. For we had found that Heat and
Cold are far from producing any such Ex-
tension and Contraction in Firr as they are
known to do in Iron. All the Experiments
we made produced differences in the length
almost imperceptible. From some of them
I was even inclined to think, that Wood is
by the Cold rather lengthned than contract-
ed; whether it is that a little Sap remaining
in those pieces of Wood we made trial with,
might possibly freeze and swell as liquids
do when they are exposed to the Cold, and
thus communicate somewhat of their Ex-
tension to the Wood. Mr. *Camus's* care in
adjusting these Rods had been such, that
notwithstanding their great length, when
we applied their Extremities between two
pieces of Iron, the thickness of a leaf of the
finest Paper more or less, would allow them
to pass very freely or not at all.

ON

78 *A Degree of the Meridian*

Decem. ON Friday the 21st of December, the Day of the Winter Solstice, and a pretty remarkable one for such an Enterprize, we began the measure of our *Base* towards *Avafaxa*, where it lay. In this Season the Sun but just showed himself above the Horizon towards Noon. But the long Twilights, the whiteness of the Snow, and the Meteors that are continually blazing in this Sky, furnished us light enough to work four or five hours every day. At 11 in the Forenoon we left the *Curate's* House, where we had taken up our Quarters till this Work should be finished, and went upon the River to begin our Survey; attended by so many Sledges, and so great an Equipage, that the *Laplanders*, drawn by the novelty of the Sight, came down from the neighbouring Mountains. We parted ourselves into two Bands, each of which carried four of the Rods just now mentioned. I shall say nothing of the Fatigues and Dangers of this Operation. Judge what it must be to walk in Snow two foot deep, with heavy Poles in our hands, which we must be continually laying upon the Snow and lifting again: In a Cold so extreme, that whenever
we

measured at the Polar Circle. 79

we would taste a little Brandy, the only *Decem.* thing that could be kept liquid, our Tongues and Lips froze to the Cup, and came away bloody: In a Cold that congealed the Fingers of some of us, and threatned us with yet more dismal Accidents. While the Extremities of our Bodies were thus freezing, the rest, through excessive Toil, was bath'd in Sweat. Brandy did not quench our thirst; we must have recourse to deep Wells dug thro' the Ice, which were shut almost as soon as opened, and from which the Water could scarce be conveyed unfrozen to our Lips; and must thus run the hazard of the dangerous contrast which iced Water might produce in our heated Bodies.

OUR Work however advanced apace, six days labour had brought it to within about 500 Toises, where we had not been able to plant our Stakes soon enough. So we intermitted our measuring on the 27th, which Messrs *Clairaut*, *Camus* and *le Monnier* were to employ in planting these Stakes, while the *Abbé Outhier* and I went out upon an extraordinary enough Adventute.

LAST

Decem. LAST Summer we had omitted an Observation of very small moment, and which might have been overlooked in a Country where the making Observations was less troublesome than here. We had forgot to take the height of an Object that we made use of in measuring, from the Top of *Avasaxa*, the Angle between *Cuitaperi* and *Horrilakero*. And to measure this height, I undertook to go with a Quadrant to the top of the Mountain; so scrupulously careful were we that nothing should be wanting to the perfection of our Work. Imagine a very high Mountain, full of Rocks, that lie hid in a prodigious quantity of Snow, as well as their Cavities, wherein you may sink thro' a Crust of Snow as into an Abyfs, and the Undertaking will appear scarce possible. Yet there are two ways of performing it. One is by walking, or rather sliding along, upon two strait Boards eight foot in length, which the *Finlanders* and *Laplanders* use to keep them from sinking into the Snow. But this way of walking requires long practice. The other is by trusting yourself to a *Rain-Deer*, who is used to perform such Journeys.

THE Machine which these Animals *Decent.* draw is a sort of Boat scarce large enough to hold the half of one's Body. As this travelling in the Snow is a kind of Navigation, that the Vessel may suffer the less resistance in its Course, it has a sharp Head and a narrow Keel, like an ordinary Boat; and on this Keel it tumbles so from side to side, that if one takes not good care to ballance himself, it will be in danger of over-setting every moment. It is fixt by a thong to the Collar of the Rain-Deer, who, as soon as he finds himself on a firm beaten Road, runs with incredible Fury. If you would stop him, it avails little to pull a sort of Rein which is tied to his Horns. Wild and unmanageable, it will only make him change his Track, or perhaps turn upon you, and revenge himself by kicking. If this happens to a *Laplander*, he turns the Boat over him, and uses it as a Buckler against the Attacks of the Rain-Deer. But as we were Strangers to this Adresse, we might have been killed before we could put ourselves in such a posture of Defence. Our only Defence was a little Stick each of us had got in his hand, by way of Rudder

82 *A Degree of the Meridian*

Decem. to steer our Course, and keep clear of the Trunks of Trees. In this manner was I to climb *Avafaxa*, accompanied by the Abbé *Outhier*, two Men and a Woman of the Country, and Mr. *Brunnius* their Curate.

THE first part of our Journey was done in a moment; our flight over the plain beaten Road from the Curate's House to the foot of the Mountain can be compared only to that of Birds. And tho' the Mountain, where there was no track, very much abated the speed of our Rain-deer, they got at length to the top of it; where we immediately made the Observation for which we came. In the mean time our Rain-deer had dug deep holes in the Snow, where they browsed the Moss that covers the Rocks. And the *Laplanders* had lighted a great Fire, at which we presently joined them to warm ourselves. The Cold was so exceeding great, that the Heat of this Fire could reach but to a very small distance. As the Snow just by it melted, it was immediately froze again, forming a hearth of Ice all round.

IF our Journey up hill had been painful, our Concern now was lest our return should

measured at the Polar Circle. 83

should be too rapid. We had to come down *Decem.*
a steep, in Conveyances, which, though partly
funk in the Snow, slid on notwithstanding,
drawn by Animals whose Fury in the Plain
we had already try'd, and who, though
sinking in the Snow to their Bellies, would
endeavour to free themselves by the Swift-
ness of their flight. We very soon found
ourselves at the bottom of the Hill; a mo-
ment after, all this great River was crossed,
and we back at the Curate's House.

NEXT day we finished our Survey;
and had now no reason to regret the Toils
we had gone thro', when we saw what sur-
prizing exactness the measuring upon a Sur-
face of Ice had given us. The difference
between the Measures of our two Compa-
nies was but four Inches upon a distance of
7406 Toises 5 feet. An exactness not to
be expected, and almost incredible. We
look upon it as an effect of Chance, and
that there must have been greater differences,
but which in the course of our Work had
compensated each other; for this small dif-
ference of four Inches rose all in our last
day's measuring. Each of our Bands had
measured every day the same number of

84 *A Degree of the Meridian*

Decem. Toises; and the difference every day was but one Inch which the one or the other had gained. This coincidence, which was owing partly to the Ice, and partly to our own Accuracy, shewed at the same time the perfect equality of our *Rods*; for the smallest difference in their lengths, must, in so great a distance, have been multiplied to a considerable Sum.

WE already knew the *Amplitude* of our Arc; and our Figure, every other way determined, wanted only to be applied to its *Scale*, that is, to the length of our Base. This we were now Masters of; and immediately found that the length of the Arc of the Meridian intercepted between the two Parallels that pass through the Observatories of *Torneå* and *Kittis* is $55023 \frac{1}{4}$ Toises. That the *Amplitude* of this Arc being $57^{\circ} 27''$. the Degree of the Meridian at the Polar Circle is greater by 1000 Toises than it should be according to Mr. *Cassini*, in his *Treatise On the Magnitude and Figure of the Earth*.

THIS Operation ended, we made haste to get back to *Torneå*, to secure ourselves

selves the best we could against the growing *Decem.*
Severity of the Season.

THE Town of *Torneå*, at our Arrival on the 30th of *December*, had really a most frightful Aspect. Its little Houses were buried to the tops in Snow, which, if there had been any day-light, must have effectually shut it out. But the Snows, continually falling, or ready to fall, for most part hid the Sun the few moments that he might have showed himself at Mid-day. In the Month of *January* the Cold was increased to that extremity, that Mr. *Reaumur's* Mercurial Thermometers, which at *Paris*, in the great Frost of 1709, it was thought strange to see fall to 14 Degrees below the freezing point, were now got down to 37. The Spirit of Wine in the others was frozen. If we opened the door of a warm room, the external Air instantly converted all the Vapour in it into Snow; whirling it round in white Vortexes. If we went abroad, we felt as if the Air were tearing our Breasts in pieces. And the cracking of the Wood whereof the Houses are built, as the violence of the Cold split it, continually alarmed us with an approaching in-

Decem; crease of Cold. The Solitude of the Streets was no less than if the Inhabitants had been all dead: And in this Country you may often see People that have been maimed, and had an Arm or a Leg froze off. The Cold, which is always very great, increases sometimes by such violent and sudden Fits, as are almost infallibly fatal to those that happen to be exposed to it. Sometimes there rise sudden Tempests of Snow, that are still more dangerous. The Winds seem to blow from all Quarters at once, and drive about the Snow with such Fury, that in a moment all the Roads are lost. Unhappy he who is surprized by such a Storm in the Fields, His Acquaintance with the Country, or the Marks he may have taken by the Trees, cannot avail him. He is blinded by the Snow, and lost if he stirs but a step.

IF the Earth in this Climate is thus horrible, the Heavens present to the Eye a most beautiful Prospect. As soon as the Nights begin to be dark, Fires of a thousand Colours and Figures light up the Sky, as if designed to compensate, to a Country accustomed to such length of day, the absence of the Sun in this Season. These Fires have not here,

measured at the Polar Circle. 87

as in the more southerly Climates, any con- *Decem.*
stant Situation. Though you may often
see a luminous Arch fixed towards the North,
they seem more frequently to possess the
whole Extent of the Hemisphere. Some-
times they begin in the form of a great Scarf
of bright Light, with its Extremities upon
the Horizon, which, with a Motion re-
sembling that of a Fishing-Net, glides swift-
ly up the Sky; preserving in this Motion a
direction nearly perpendicular to the Meri-
dian. Most commonly, after these Preludes,
all the Lights unite at the Zenith, and
form the top of a sort of Crown. Arcs
like those we see towards the North in
France, are here frequently situated towards
the South: And oftentimes towards both
North and South at once. Their Summits
approach each other, while the distance of
their Extremities widens towards the Hori-
zon. I have seen some of the opposite Arcs
whose Summits almost joined at the Ze-
nith: And both the one and the other have
frequently several concentric Arcs beyond it.
Their tops are all placed in the Direction
of the Meridian, though with a little Declin-
ation to the West; which I did not find
to be constant, and which sometimes is in-
G 4 sensible.

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Jan^r, sensible. Some of these Arcs have their
 1737. greatest width at the Horizon; which contracting as they rise, gives them the form of more than half a great Ellipse. It were endless to mention all the different Figures these Meteors put on, and the different Motions wherewith they are agitated. Their Motion is most commonly like that of a pair of Colours waved in the Air, and the different Tints of their Light give them the appearance of so many vast Streamers of that sort of Taffetas which we call *changeable*. Sometimes they line a part of the Sky with Scarlet. On the 18th of *December* I saw at *Osaver-Torneå* a Phenomenon of this kind, which raised my Admiration, in the midst of all the Wonders I was now every day accustomed to. There appeared to the South, a great space of the Sky tinged with so lively a red, that the whole Constellation of *Orion* look'd as if it had been dipt in blood. This Light, which was fixt at first, soon moved, and changing into other colours, Violet and Blue, settled into a Dome, whose top stood a little to the South-west of the Zenith. The Moon shone bright, but did not in the least efface it. In this Country, where there are Lights of so many
 disse-

different colours, I never saw but two that *Jan^r*, were red; and such are taken for Presages of some great Misfortune. After all, when People look at these Phenomena with an unphilosophic eye, it is not surprizing if they discover in them fiery Chariots, Armies engaged, and a thousand other Prodigies.

WE had shut our selves up at *Torneå* in a kind of inaction, till the Month of *March* that we could venture out upon new Discoveries.

IN the mean time, the great difference of our Arc, from what it must have come out upon Mr. *Cassini*'s Hypothesis, astonished us; and we resolved, however incontestable our Operations were, to submit the whole Process to a most rigorous Examination.

AS for our Triangles, their Angles had been observed so often, and by so great a number of Persons, that this part of our Work could fall under no manner of suspicion. It had even an advantage above any thing that has been done in this kind. It has commonly been thought sufficient to find two Angles of a Triangle by Observation, and the third by subtracting their Sum,

90 *A Degree of the Meridian*

Jan^r. Sum from 180 Degrees. This Method would have been extremely convenient for us, and would have saved us many a disagreeable hour upon the tops of these Mountains; yet we had willingly sacrificed this Convenience to the pleasure of knowing from actual Observation every Angle in our Figure.

BESIDES, tho' to determine the Distance between *Torneå* and *Kittis*, no more than 8 Triangles were absolutely necessary, we had observed several supernumerary ones, and by this means our Heptagon furnished us Combinations or Series of Triangles without number.

THUS one part of our Work had been done, one may say, a great many times over; and there remained only to calculate and find what different Lengths might result from these different Series of Triangles. We had the patience to make trial with no less than 12 Series; and though several of our Angles were too small to be admitted in such Calculations, the highest difference in the distances of *Kittis* and *Torneå*, deduced from these Series, rose but to 54 Toises. We pitched upon two, which we judged preferable

ferable to the others, and which gave a difference of $4\frac{1}{2}$ Toises. And the *Mean* of this we used to determine the Length of our Arc.

SUCH a perfect Agreement would have surprized us, if we had not remembred what pains and time had been bestowed upon the taking of these Angles. Eight or nine Triangles had cost us 63 days; and every Angle had been observed so often, and by so many different Persons, that the *Mean* of them all could not but come very near the Truth.

THE small number of our Triangles enabled us to make an odd enough Calculation, which gives the strict limits of all the Errors that bad skill and bad luck put together can produce. We made a supposition, that in every Triangle we had committed an Error in two of the Angles of $20''$ each, and in the third of $40''$; and that all these Errors lay the same way, tending always to diminish our Arc. And having made a computation upon this strange Supposition, we found that the Error could amount to but $54\frac{1}{2}$ Toises,

OUR

Jan'y.

OUR extreme Care in measuring the Base left no room to suspect we had failed in this part. The agreement of so many skilful Persons, who writ down, each separately, the number of Rods, and the repeating of this Measure with a difference of no more than 4 Inches, were a more than sufficient security.

WE turned therefore the rest of our Scrutiny upon the *Amplitude* of the Arc. The small difference there was amongst our Observations, both at *Kittis* and at *Torneå*, left no doubt as to the manner of Observing.

AND considering the Solidity and Construction of our Sector, with the Precautions we had taken in carrying it from Place to Place, there was no great ground to fear it had met with any accident to put it out of order.

ITS Limb, Telescope and Centre, make up but one Piece, and the Threads in the Focus of the Object-Glass, are two Silver Wires, fixed by Mr. *Grabam* himself, so as they can suffer no change in their situation, and remain

always

always in the same degree of Tension, whether it is hot or cold. Thus the only disorder that could happen to this Instrument would be the bending of its Telescope. *Janr.*

BUT upon calculating the effects of any Alteration of this sort, it will appear, that to occasion an Error of one Second in the Amplitude of our Arc, there must be a bending so considerable as to be very easily perceived. Inclosed in a strong Case it had been conveyed in a Boat from *Kittis* to *Torneå*, under the care of one of us, put on shore at the Cataracts, and carried by Men.

THE situation of the Star which we had observed, ensured us against what happens to the Telescopes of large Instruments, when they are directed to an Object at a considerable distance from the Zenith; their weight alone must bend them while they are in this inclined Position: and the method of observing with the two different Sides of the Instrument, tho' it may prevent some other Mistakes, cannot correct this. For if in observing with the face of the Instrument towards the East, the Telescope has suffered any Inflexion, when you turn its face to the West,

94 *A Degree of the Meridian*

Jan^r. West, it will suffer nearly the same Inflection the contrary way; so that the same Point may answer to the Zenith in either Observation, and yet the Star's distance from the Zenith not be justly measured. The distance of our Star from the Zenith of *Kittis* was but half a Degree, and consequently our Telescope, in a situation so erect, could suffer no alteration.

THOUGH, on all these accounts, we had no reason to doubt of our Amplitude's being accurately measured; yet we would be assured by experience that it was so; and for this purpose employed a Method which was indeed the most troublesome, but must be at the same time the most satisfactory, as it would at once discover to us the goodness of our Instrument, and how far we might depend upon the Accuracy of our Observations.

THIS Verification consisted in determining the same Amplitude by the means of another Star. We watched therefore an occasion of making some Observations near one another, which is difficult in a Country where there are seldom three or four clear Nights together.

And

And on the 17th of *March* 1737, having be- *March.*
gun, at *Torneå*, in the same place as before,
to observe α of the *Dragon*, and got three
good Observations of this Star; we set out
for *Kittis* to make the like Observations there.
Our Sector was conveyed upon a Sledge that
went very slowly upon the Snow; the soft-
est Carriage that can be imagined. Our new
Star was nearer still to the Zenith than the
former, being situated but a quarter of a De-
gree from the Zenith of *Torneå*.

WE could readily place our Instrument
by means of the Meridian Line that had been
drawn in our Observatory at *Kittis*; and
the 4th of *April*, began our Observations of *April.*
 α ; three of which compared with those of
Torneå, gave for the Amplitude $57^{\circ} 30' \frac{1}{2}$,
which exceeds that found by the Star δ by
 $3' \frac{1}{2}$; allowance being made for the Aberra-
tion of Light: and if the Aberration is not
taken into the account, the difference would
not be $1''$.

A difference so very inconsiderable, that it
might be owing to the Errors in observing,
and which, as will appear from the Sequel, was
still less than it appeared, was a strong Proof
both

96 *A Degree of the Meridian*

April. both of the goodness of the Instrument, and of the truth of our Observations.

TAKING now a *Mean* between the Amplitude found by the Star δ and that found by α , the true Amplitude comes to be $57^{\circ}. 28'' \frac{3}{4}$, which compared with the measured Length of $55023 \frac{1}{2}$ Toises, gives for the Degree that cuts the Polar Circle, 57437 Toises, exceeding that of Mr. *Picard* between *Paris* and *Amiens* by 377 Toises.

BUT it must be observed, that the *Aber-ration* of the fixt Stars was not known, nor could be taken into the account by Mr. *Picard*. If his *Amplitude* is corrected by it, and by the *Precession* of the *Equinoxes* and *Refraction*, both which he had neglected, it will be $1^{\circ}. 23'. 6'' \frac{1}{4}$, which compared with the distance measured 78850 , gives to a Degree 56925 , short of ours by 512 Toises.

AND if the *Aberration* was set aside, our Amplitude would be reduced to $57^{\circ}. 25''$, which compared with the Arc would give to the Degree 57497 , exceeding 57060 Toises, which Mr. *Picard* had found in a Degree,

measured at the Polar Circle. 97

Degree, without reckoning the *Aberration April*, by 437.

LAST of all; with the *Aberration*, our Degree differs by 950 Toises from what it should be by Mr. *Cassini's* Book; and setting aside the *Aberration*, by 1000.

WHENCE it is evident, *That the Earth is considerably flattened towards the Poles.*

DURING our whole Stay in the *frigid Zone*, the Cold was so excessive, that the 7th of *April* at 5 in the Morning, the Thermometer was fallen to 20 Divisions below the Point of Freezing, although every Afternoon it rose two or three Divisions above it: a difference of height not much less than that which the greatest Heats and Colds that are felt at *Paris* usually produce in the Thermometer. Here, in the space of 12 hours, we had all the variety that is felt in the temperate Zones in a whole Year.

WE carried our Scrutiny even to the direction of the Heptagon, with respect to the Meridian. This Direction, as above mentioned, had been determined upon *Kittis* by

H

a

98 *A Degree of the Meridian*

April. a great number of Observations of the Sun's Passage by the Verticals of *Niemi* and *Pullingi*, and it was not probable we had misplaced our Figure, the Triangles that composed it being so few in number, and the Sum of its Angles coming so near to just 900 Degrees: yet we chose to settle this Point once more, at *Torneå*.

WE took a different Method from that which we had used at *Kittis*. We measured the Angle between the Sun in the Horizon, and one of our Signals, marking the time of the Observation: and three such Observations gave us, at a *mean*, the same Angle, within 34", as we had found at *Kittis*.

HAVING thus gone over every part of our Work a second time, it remained only to examine the original Construction and Division of our Sector. There was not the least reason to suspect it; but having some leisure till the Season for travelling should come on, we would employ a part of it in this Examination. Our Method deserves a particular Description, being singular; and of use to shew what may be expected from
such

measured at the Polar Circle. 99

such an Instrument, and how to discover *May.*
any Alteration it may chance to receive.

THE 4th of *May*, we laid out (still upon the Ice of the River) a Radius of 380 Toises, 1 Foot, 3 Inches, 0 Line; having measured it twice without finding any difference. We planted two firm Posts with two *Marks* in a Line perpendicular to the Extremity of this Radius, and having measured the distance between the Centers of the two *Marks*, we found it to be 36 Toises, 3 F. 6 In. $6\frac{1}{3}$ Lin. This Line was our Tangent.

WE placed the Sector horizontally in a Room, upon two firm Supports that rested upon a Vault, so that its Center was precisely at the Extremity of our Radius of 380 Toises, 1 F. 3 Inches; and five of us having severally taken the Angle between the two Marks, the greatest difference amongst our Observations not amounting to full 2", their *Mean* was $5^{\circ}. 29'. 52'', 7$. Now Mr. *Graham* had signified to us that the Arch of $5\frac{1}{2}$ Degrees on the Limb of this Instrument was too short by $3''\frac{3}{4}$; subtracting these $3''\frac{3}{4}$ our Angle is $5^{\circ}. 29'. 48''. 95$. But the Angle,
H 2 by

100 *A Degree of the Meridian*

May. by Calculation, is $5^{\circ}. 29'. 50''$, differing from that observed by no more than $1'' \frac{1}{2}$.

IT may seem surprizing that a Sector which, in so temperate a Climate as that of London, was found to be of $5^{\circ}. 29'. 56'' \frac{1}{4}$, and was divided in a Room probably not cold, should at Tornea remain precisely of the same length, at the making this trial, when its parts were no doubt contracted by the Cold. But the surprize will cease, if it is remembered, that this Instrument is all of the same matter, and that consequently all its parts must be contracted proportionally, its figure remaining similar to what it was before, as we found it had done.

HAVING found the total Arc of the Sector so exquisitely just, we would next see if the two Degrees of its Limb, which we had used, the one for δ and the other for α , were perfectly equal. Mr. Camus's Adresse, to which we had been obliged upon so many other occasions, helped us to make this Comparison with all the accuracy imaginable. And taking the Mean of 5 several Observations made by different Persons, the Degree we had made use of for δ came out greater by $1''$ than that which we had used for α .

WE

May.

WE were surprized to see that this inequality of the two Degrees made the small difference between our two Amplitudes still less, reducing it from $3''\frac{1}{2}$ to $2''\frac{1}{2}$. And it will appear from the detail of our Operations, and from the Method we used to discover it, that this difference, small as it is, may be reckoned upon with great Certainty.

IN the same manner we verified not only the total Arc of the Sector, but different Arcs which we compared together. And this Verification from Arc to Arc, joined to that of the whole, satisfied us that we could neither have wished nor hoped for any thing more exquisite in its kind.

WE could not conceive any thing more that remained for us to do, with respect to the measure of a Degree of the Meridian. For I shall say nothing at present of our Experiments upon *Gravitation*; a Subject no less important than the other, and which we treated with equal care. Let it suffice to assure whoever has a mind to examine the Earth's Figure by the Weight of Bodies, after the Example of Sir *Isaac Newton*, Mr. *Huy-*

May. gens, and others (to whose Names may I be permitted to add my own) that they will find all the Experiments we made in the North to that purpose, as well as those we are told Mess^{rs} *Godin*, *Bouger*, and *la Condamine* have made at the Equator, will concur in making the Earth flat towards the Poles.

MEAN time, the Sun was now come nearer, or rather no more quitted us. It was curious enough to see him enlighten for so long a time, a whole Horizon of Ice, and to see Summer in the Heavens, while Winter still kept possession of the Earth. We were now in the Morning of that long Day of several Months ; yet the Sun, with all his assiduity, had wrought no change either upon the Ice or Snows.

THE 6th of *May* it began to rain, and some Water appeared on the Ice of the River. At Noon a little Snow melted ; but in the Evening, Winter resumed his Rights. At length, on the 10th of *May*, the Earth which had been so long hid, began to appear ; some high Points that were exposed to the Sun, shewed themselves, as the tops of the Moun-

measured at the Polar Circle. 103

Mountains did after the Deluge, and all the *June*.
Fowls of the Country returned. Towards
the beginning of *June*, Winter yielded up
both Earth and Sea. We bethought us forth-
with of our Journey back to *Stockholm*; and
set out the 9th of *June*, some of us by Land,
and others by Sea. But the Sequel of our
Adventures, and our Shipwreck in the Gulph
of *Bothnia*, belong not to the present Sub-
ject.



H 4

OBSER-



OBSERVATIONS

Made at the Polar Circle.

BOOK I.

PART I.

Containing the Operations for measuring the Degree of the Meridian.

CHAP. I.

Observations for forming the Triangles, and determining their Position, with respect to the Meridian Line.

I.

The Angles Observed.

ALL these Angles were taken with a Quadrant of 2 foot Radius, arm'd with a Micrometer; which Instrument verified several times round the Horizon, gave always the Sum of the Angles very near equal to 360° .

THE

A Degree of the Meridian, &c. 105

THE Decimals of Seconds are marked as they arose in the arithmetical Reduction of the parts of the Micrometer to Seconds; but we would not for that be thought to pretend to an imaginary Exactness.

FOLLOWS a Table of the Angles observed, with the Elevations of the Objects, where the Sign + or — marks their being *above* or *below* the Horizontal Line.

<i>Angles observed.</i>	<i>Angles reduced to the Horizon.</i>	<i>Elevations.</i>
<i>In the Spire of the Church of Torneå.</i>		
CTK... 24° 23' 0",2	24° 22' 58",8	C.....0'0" Fig. 1.
And by the Reduction on account of the Centre of the Instrument its being 5 foot distant from the Centre of the Spire in the Direction of <i>Cuitape-ri</i>		
CTK.....	24 22 54,5	
KTn... 19 38 20,9	19 38 20,1	n... + 3 0
And by Reduction for the place of the Centre of the Instrument.		
KTn.....	19 38 17,8	K... + 8 40
		The Horizon of the Sea — 11 0
		<i>Angles</i>

106 A Degree of the Meridian

Angles observed.

Angles reduced to
the Horizon.

Elevations.

Upon Niwa.

Fig. 1.

$TnK..$	$87^{\circ} 44' 24,8''$	$87^{\circ} 44' 19,4''$	$T... -17' 40''$
$HnK..$	$73^{\circ} 58' 6,5''$	$73^{\circ} 58' 5,7''$	$K... +16' 50''$
$AnK..$	$95^{\circ} 29' 52,8''$	$95^{\circ} 29' 54,4''$	$A... +4' 40''$
$AnH = AnK - HnK$	$21^{\circ} 31' 48,7''$		$H... -0' 30''$
$AnH = 21^{\circ} 32' 16,9''$	$21^{\circ} 32' 16,3''$		
Whence AnH is	$21^{\circ} 32' 2,5''$		
$CnH..$	$31^{\circ} 57' 5,2''$	$31^{\circ} 57' 3,6''$	$C... +10' 0''$

Upon Kakama.

$TKn...$	$72^{\circ} 37' 20,8''$	$72^{\circ} 37' 27,8''$	$n.... -22' 50''$
$CKn...$	$45^{\circ} 50' 46,2''$	$45^{\circ} 50' 44,2''$	$C.... -4' 45''$
$HKn..$	$89^{\circ} 36' 0,4''$	$89^{\circ} 36' 2,4''$	$H.... -5' 10''$
$HKC = nKH - CKn$	$43^{\circ} 45' 18,2''$		
$HKC..$	$43^{\circ} 45' 46,8''$	$43^{\circ} 45' 47,0''$	
$HKC..$	$43^{\circ} 45' 41,5''$	$43^{\circ} 45' 41,7''$	
Whence HKC is	$43^{\circ} 45' 35,6''$		
$CKT = CKn + nKT$	$118^{\circ} 28' 12,0''$		$T.... -24' 10''$
$HKN..$	$9^{\circ} 41' 48,1''$	$9^{\circ} 41' 47,7''$	$N.... -8' 10''$

Upon Cuitaperi.

			$K.... -6' 10''$
$KCn...$	$28^{\circ} 14' 56,9''$	$28^{\circ} 14' 54,7''$	$n.... -19' 0''$
$TCK...$	$37^{\circ} 9' 15,0''$	$37^{\circ} 9' 12,0''$	$T.... -24' 10''$
HCK	$100^{\circ} 9' 56,4''$	$100^{\circ} 9' 56,8''$	$H... -2' 40''$
$ACH..$	$30^{\circ} 56' 54,4''$	$30^{\circ} 56' 53,4''$	$A... +5' 0''$

Angles

measured at the Polar Circle. 107

<i>Angles observed.</i>	<i>Angles reduced to the Horizon.</i>	<i>Elevations.</i>
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Upon Avafaxa.

<i>HAP..</i> 53 45 58,1	53 45 56,7	<i>P....</i> + 4 50
<i>HAX...</i> 24 19 34,8	24 19 35,0	<i>H....</i> — 8 0
<i>xAn...</i> 77 47 46,7	77 47 49,5	<i>x....</i> —10 40
<i>xAC...</i> 88 2 11,0	88 2 13,6	<i>C....</i> —14 15
<i>HAn=HAX+xAn</i>	102 7 24,5	<i>n....</i> —20 20
<i>HAC=CAx+xAH</i>	112 21 48,6	
<i>CAn...</i> 10 13 54,2	10 13 52,8	

Upon Pullingi.

<i>APH..</i> 31 19 53,7	31 19 55,5	<i>H....</i> —22 0
<i>QPN</i> 87 52 9,7	87 52 24,3	<i>A....</i> —18 10
<i>NPH</i> 37 21 58,9	37 22 2,1	<i>Q....</i> —32 40
		<i>N....</i> —26 50

Upon Kittis.

<i>NQP..</i> 40 14 57,3	40 14 52,7	<i>P....</i> +22 30
		<i>N...</i> + 1 0

Upon Niemi.

<i>PNQ</i> 51 53 13,7	51 53 4,3	<i>P....</i> +18 30
<i>PNH</i> 93 25 8,1	93 25 7,5	<i>Q....</i> —14 0
<i>HNK</i> 27 11 55,3	27 11 53,3	<i>H...</i> — 2 40
		<i>K....</i> —14 0

Angles

108 *A Degree of the Meridian*

<i>Angles observed.</i>	<i>Angles reduced to the Horizon.</i>	<i>Elevations.</i>
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Upon *Horrilakero*.

<i>CHn...</i>	19° 38' 21",8	19° 38' 21",0	<i>n...</i>	— 18' 15"
<i>CHA...</i>	36 42 4,3	36 42 3,1	<i>A...</i>	0 0
<i>AHP...</i>	94 53 49,7	94 53 49,7	<i>P...</i>	+ 11 50
<i>PHN...</i>	49 13 11,9	49 13 9,3	<i>N...</i>	— 5 0
<i>KHn...</i>	16 26 6,7	16 26 6,3	<i>K...</i>	— 12 30
<i>CHK...</i>	36 4 54,1	36 4 54,7	<i>C...</i>	— 10 40

Angles for connecting the Base Bb with the Tops of Avafaxa and Cuitaperi.

Angles observed.	Angles reduced to the same Plan.	Elevations of the Objects seen from the Point B.
<i>ABb</i> ... 9° 21' 58",0 <i>AbB</i> .. 77 31 48,1 <i>BAb</i> .. 93 6 7,2	Reducing <i>ABy</i> , <i>yBC</i> , and <i>ABz</i> , <i>zBC</i> to the same Plan <i>ABC</i> , and taking a Mean between the two Values of <i>ABC</i> thus found, we had <i>ABC</i> .. 102° 42' 13",5	<i>A</i> .. + 0° 40' 30" <i>y</i> ... + 1 23 30 <i>C</i> .. + 1 4 5 <i>z</i> ... + 1 11 0
<i>ABy</i> .. 61 30 5,4 <i>yBC</i> .. 41 12 3,4 <i>ABz</i> .. 46 7 57,5 <i>zBC</i> .. 56 34 22,2		
<i>ACB</i> .. 54 40 28,8 <i>BAC</i> .. 22 37 20,6		

The Letters *x*, *y*, *z*, mark the intermediate Objects that were used to take the Angle *ABC* at twice, being greater than 90°.

II.

Observations upon Kittis for drawing the Meridian Line.

THE Instrument with which these Observations were made consisted of a Telescope 15 Inches long, moveable round a horizontal Axis to which it was perpendicular. This Instrument was placed upon the Centre of the Signal of *Kittis*, where the height of the Pole is $66^{\circ}.48'.20''$. and whose Longitude East from *Paris* answers, we suppose in that Calculation, to $1^{\text{h}}.23'$.

THERE was in the same place a Clock which we regulated every day by correspondent Altitudes of the Sun. And the Hour of the passage of the Sun's Centre, which we determined by the passages of his two Limbs, is in this Table given in *true time*.

110 *A Degree of the Meridian*

Passages of the Sun's Centre by the Vertical of the Signal of Pullingi.

1736. Afternoon.

	h	'	"	☉'s Decl.	°	'	"
30 Septemb. at	1	49	49	☉'s Decl.	3	0	40
1 October at	1	50	7 $\frac{1}{4}$	☉'s Decl.	3	24	1
2 October at	1	50	26	☉'s Decl.	3	47	19
7 October at	1	51	54 $\frac{3}{4}$	☉'s Decl.	5	42	56
8 October at	1	52	14 $\frac{1}{2}$	☉'s Decl.	6	6	10

Passages of the Sun's Centre by the Vertical of the Signal of Niemi.

1736. Before noon.

	h	'	"	☉'s Decl.	°	'	"
4 October at	11	16	37	☉'s Decl.	4	31	22
7 October at	11	16	15 $\frac{3}{4}$	☉'s Decl.	5	40	26
8 October at	11	16	12	☉'s Decl.	6	3	39



CHAP.



CHAP. II.

*The Angles formed by the Meridian
Line with the Lines drawn from
Kittis to Pullingi, and to Niemi.*

THE Method we used, to find from Fig. 3. these Observations, the above-mentioned Angles, consists in resolving the two spherical Triangles PZS , PZs , where we have given; the Side $PZ = 23^{\circ}. 11'. 40''$. being the distance of the Zenith of *Kittis* from the Pole; PS or Ps , the Compliment of the Sun's Declination at the time of Observation; and the Angle ZPS or ZPs , which is known from the time of the Sun's passage by the Vertical Zp or ZN of *Pullingi* or *Niemi*: Whence are found the Angles HZp and HZN , or $H\mathcal{Q}p$ and $H\mathcal{Q}N$, which Lines drawn from *Kittis* to *Pullingi* and *Niemi* make with the Meridian.

THE

112 *A Degree of the Meridian*

THE Angles deduced from the several Observations are as follows:

The Decl. of *Pullingi*, Decl. of *Niemi*, East, West.

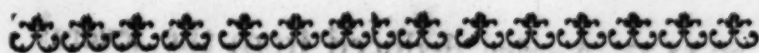
30 Sept.	28° 51' 54"	
1 Octob.	28° 51' 56"	
2 Octob.	28° 52' 5"	
4 Octob.		11° 23' 30"
7 Octob.	28° 51' 43"	11° 23' 23"
8 Octob.	28° 52' 6"	11° 22' 31"

Fig. 3. AND having already (*page* 107.) the Angle $NQP = 40^{\circ}. 14', 52'', 7$, these Declinations of *Niemi* are changed by subtraction into the following of *Pullingi*.

28° 51' 23"
28° 51' 30"
28° 52' 22"

AND all these Declinations give, at a Mean, the Declination of *Pullingi*, or the Fig. 2. Angle $PMQ = 28^{\circ}. 51'. 52'$.

CHAP.



C H A P. III.

The Length of the Base; and the Calculation of the Triangles of the two principal Series.

I.

The Length of the Base.

Bb is the Base. It was measured two se- Fig. 1.
veral times by two different Companies,
whereof each had four Perches of 30 foot
in Length.

	<i>Tois.</i>	<i>f. inch.</i>
The first Mensuration gave	7406	5 0
The second	7406	5 4
Between which the mean length is	} 7406	5 .2

I

II. Cal-

114 *A Degree of the Meridian*

II.

*Calculation of the two Triangles with which
all the Series begin.*

A B b.

	<i>Angles observed.</i>	<i>Angles corrected for Calculat.</i>
Fig. 1. <i>ABb...</i>	9 21 58,0	9 22 0
<i>AbB...</i>	77 31 48,1	77 31 50
<i>BAb...</i>	93 6 7,2	93 6 10
	179 59 53,3	180 0 0

A B C.

<i>ABC...</i>	102 42 13,5	102 42 12
<i>BAC...</i>	22 37 20,6	22 37 20
<i>ACB...</i>	54 40 28,8	54 40 28
	180 0 2,9	180 0 0

BY resolving these two Triangles, the
Base B b being 7406 Toises, 5 Foot, 2 In-
ches, the distance *AC*, between *Avafaxa*
and *Cuitaperi* is found to be 8659,94 Toises.

AND these two Triangles having been
very accurately determined, and their dis-
position advantageous for finding this di-
stance, *AC* may be henceforth used as a
Base.

III. Cal-

III.

Calculation of the Triangles of the first Series.

A C H.

Angles observed, reduced to the Horizon.			Angles corrected for Fig. 2. Calculation.		
CAH...	112° 21' 32,9"		112° 21' 17"		
ACH...	30 56 53,4		30 56 47		
AHC...	36 42 3,1		36 41 56		
	180 0 29,4		180 0 0		

C H K.

CHK...	36 4 54,7		36 4 46		
CKH...	43 45 35,6		43 45 26		
KCH...	100 9 56,8		100 9 48		
	180 0 27,1		180 0 0		

C K T.

KCT...	37 9 12,0		37 9 7		
CKT...	118 28 12,0		118 28 3		
CTK...	24 22 54,3		24 22 50		
	180 0 18,3		180 0 0		

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AHP.

AHP...	94	53	49,7	...	94	53	56
HAP...	53	45	56,7	...	53	46	3
APH...	31	19	55,5	...	31	20	1
	179	59	41,9		180	0	0

HNP.

HNP...	93	25	7,5	...	93	25	1
NHP...	49	13	9,3	...	49	13	3
HPN...	37	22	2,1	...	37	21	56
	180	0	18,9		180	0	0

NPQ.

NPQ...	87	52	24,3	...	87	52	17
NQP...	40	14	52,7	...	40	14	46
PNQ...	51	53	4,3	...	51	52	57
	180	0	21,3		180	0	0

TAKING $AC = 8659,94$ Toises,
as found above (*page 114.*) by means of the
two Triangles ABb , ABC ; by resolving
the foregoing Triangles we find,

Toises.

$$AP = 14277,43$$

$$PQ = 10676,9$$

$$CT = 24302,64$$

THESE

measured at the Polar Circle. 117

THESE Lines form with the Meridian the following Angles,

$$PQD = 61^{\circ} 8' 8''$$

$$APE = 84^{\circ} 33' 54''$$

$$ACF = 81^{\circ} 33' 26''$$

$$CTG = 69^{\circ} 49' 8''$$

AND the Resolution of the right-angled Triangles DQP , APE , ACF , CTG , gives for the parts of the Meridian Line,

Toises.

$$PD = 9350,45$$

$$AE = 14213,24$$

$$AF = 8566,08$$

$$CG = 22810,62$$

$$QM = 54940,39$$

for the Arc of the Meridian which passes thro' *Kittis*, and which is terminated by the Perpendicular drawn from *Torneå*.

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IV. H

Calculation of the Triangles of the second Series.

ACH.

Angles observed, reduced to the Horizon.

Angles corrected for Calculation.

Fig. 2.

<i>ACH...</i>	30 56 53,4	...	30 56 47
<i>CAH...</i>	112 21 32,9	...	112 21 17
<i>AHC...</i>	36 42 3,1	...	36 41 56
	180 0 29,4		180 0 0

CHK.

<i>CHK...</i>	36 4 54,7	...	36 4 46
<i>CKH...</i>	43 45 35,6	...	43 45 26
<i>KCH...</i>	100 9 56,8	...	100 9 48
	180 0 27,1		180 0 0

CKT.

<i>CKT...</i>	118 28 12,0	...	118 28 3
<i>CTK...</i>	24 22 54,3	...	24 22 50
<i>KCT...</i>	37 9 12,0	...	37 9 7
	180 0 18,3		180 0 0

HKN.

H K N.

HKN...	9 41 47,7	...	9 41 50
HNK...	27 11 53,3	...	27 11 56
KHN...	143 6 3,2	...	143 6 14
	179 59 44,2		180 0 0

H N P.

HNP...	93 25 7,5	...	93 25 1
HPN...	37 22 2,1	...	37 21 56
NHP...	49 13 9,3	...	49 13 3
	180 0 18,9		180 0 0

N P Q.

NPQ...	87 52 24,3	...	87 52 17
NQP...	40 14 52,7	...	40 14 46
PNQ...	51 53 4,3	...	51 52 57
	180 0 21,3		180 0 0

STILL making use of

Toifes.

$$AC = 8659,94$$

we have by the Resolution of these last Triangles,

Toifes.

$$QN = 13564,64$$

$$NK = 25053,25$$

$$KT = 16695,84$$

I 4

WHICH

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WHICH Lines make with the Meridian Line,

$$N\mathcal{Q}d = 78^{\circ} 37' 6''$$

$$KNL = 86^{\circ} 7' 12''$$

$$KTg = 85^{\circ} 48' 7''$$

THE Resolution of the Triangles $\mathcal{Q}Nd$, KNL , KTg , gives for the parts of the Meridian Line,

$$Nd = 13297,88 \text{ Toises.}$$

$$KL = 24995,83$$

$$Kg = 16651,05$$

$$\mathcal{Q}M = 54944,76$$

The other Series gave $\mathcal{Q}M = 54940,39$

Whence at a Mean $\mathcal{Q}M = 54942,57$

CHAP.



C H A P. IV.

*To determine the true Length of an
Arc of the Meridian, its Ampli-
tude being known.*

I.

THE Places of our Observatories an- Fig. 2.
swering to the Centre of the Sector,
when we made our Observations upon the
fixt Stars, were that of *Torneå* more Souther-
ly by 73 Toises, 4 foot, $5\frac{1}{2}$ inches, than
the point *T*, (the Spire of the Church, and
Vertex of our first Triangle); this distance
was measured upon the Ice of the River by
letting fall Perpendiculars: And that of
Kittis more to the North than the Centre
of our Signal *Q*, by 3 Toises, 4 foot, 8 in-
ches.

ADDING then to *QM*, these two
distances, we have $qm = 55020,09$ Toises.

II. THIS

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II.

THIS Line $q m$ is not precisely the Arc of the Meridian answering to the difference of Latitude.

FOR the perpendicular $t m$ is not the Arc of the Parallel that passes through t : Supposing the Arc $t \mu$ to be this Parallel, to find the point μ , draw the Tangent $t v$, and divide the distance $m v$ equally.

TO find the Value of $m v$, first compute the length of $m t$, in the present case nearly equal to $M T$, which, by the Resolution of the foregoing Triangles, will be found to be 3149,5 Toises: From this Line found, and the Latitude of *Tornea* given, supposing likewise (which can here occasion no sensible Error) that the Earth is spherical, and that a Degree contains 57000 Toises; the Angle made by the Tangents of the two Meridians that pass through Q and T , that is the Angle $m t v$, will easily be found to be $7'.24''$. Whence $m v$ is 6,76 Toises, and its half 3,38 Toises $= m \mu$, added to the distance $q m$, gives for the Arc of

measured at the Polar Circle. 123
of the Meridian, whose Amplitude was observed, $q\mu = 55^{\circ}23,47$ Toises.



CHAP. V.

Observations to determine the Amplitude of the Arc of the Meridian, terminated by the Parallels that pass through Kittis and Tornea.

I SHALL not at present give a complete Description of the Instrument we made use of; that would carry me too far, and is reserved for another Work. I shall endeavour only to explain what is peculiar to this Instrument, and give my Readers such a Notion of it as may enable them to understand the tryals we made of its goodness as well as the Observations themselves.

A Brass Telescope, of a considerable thickness, and about nine foot long, forms the Radius of a Limb of $5^{\circ}\frac{1}{2}$. This Limb has upon it two Divisions, both of them from $7^{\circ}\frac{1}{2}$ to $7^{\circ}\frac{1}{4}$; the one to a shorter Radius, marked

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marked with greater points ; the other to a longer Radius marked with smaller. At the Focus of the Telescope two Silver Wires cross each other ; Mr. *Graham* himself had fixt them in the firmest manner ; and contrived, by means of two Springs, to keep them always in the same degree of tension, that they may not be subject to the least Alteration. This Telescope, the Centre to which the Plumb-line is hung, and the Limb, are all one piece, and properly make up the whole Instrument ; which will not therefore be so readily put out of order as one whose Centre can be taken off. It is suspended by by two cylindric Pins, that resting upon two Brass Supports, allow it to swing freely like a Pendulum. One of the Pins ends in a very small Cylinder ; which is still more diminished where it meets the plane of the Limb, whose Centre it is. At this point of the Axis of the Pin is suspended the Plummet. And round the same Axis the Telescope moves ; while its Limb, by the means of two Wheels, slides along another immoveable Limb, which is fixt to a large Beam that passes through the middle of a great wooden Pyramid that supports the Instrument. To the immoveable Limb is
fixt

measured at the Polar Circle. 125

fixt the Micrometer, at the place most convenient for the Observation that is to be made. The use of the Micrometer is as follows:

THE immoveable Limb, and that of the Sector being placed in the Plane of the Meridian, the Telescope, as it hangs upon its Pins, would rest in a vertical Situation, But a small weight hung upon a Thread that passes over a Pulley, draws it Southward: While the Micrometer pushes it the contrary way, by means of a point of Steel that rests against a piece of hard polisht Steel, fixt upon the Telescope. The motion of this Point towards the Mirror or from it, is regulated by a very fine Screw; making the Telescope describe small Arcs; while two Indexes mark the number of Revolutions, with the parts of a Revolution, by which the Point has advanc'd or retir'd. These Revolutions measure then the Amplitude of the Arc observed, provided it is known how many Minutes and Seconds answer to one Revolution, by which the Point of the Micrometer goes backward or forward.

THE

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THE proportion of the Number of Revolutions to the Arcs must vary as the place where the Point rests upon the Speculum is higher or lower ; and therefore on a Plate of Brass that covers the Speculum when it is not made use of, there is drawn a Line marking where the Point of the Micrometer ought to rest, so as to make the Revolutions of a determinate proportion to the Arcs. You may place the Point higher and lower till you get it exactly upon the Line: And then you have the situation of the Micrometer, upon which the Proportion is regulated.

IN observing, the first thing we did was to place exactly under the Thread of the Plummet that point of the Limb which was nearest to where we knew the Plummet must cut in the time of Observation, the Ball of the Plummet being in the mean time immersed in a Vessel fill'd with Brandy. And this can be done to such an Accuracy, by the help of the Micrometer and a Microscope, on whose Focus the Light strikes perpendicularly to the Limb, that placing and displacing the Thread several times,

times, you will rarely find one Division of the Micrometer, that is to say, one Second of Difference. When the Thread, instead of hanging freely, rested upon Pegs, as in the tryals we made for verifying the Instrument, we seldom had more than $\frac{1}{4}$ of a Second's Difference between one placing and another. An Accuracy which may seem incredible to such as have never seen an Instrument like ours; but they will be better able to judge of it when they have considered the Observations made with it by so many different Persons.

BEFORE the Star was to pass the Meridian, we wrote down the Division which was marked by the Micrometer, when the Thread exactly cut the Point upon the Limb. And just as the Star past the Meridian, the Observer, without being able to see the Micrometer, turned the Skrew, till he saw the Star bisected in the Telescope, by the Thread that is perpendicular to the Limb. Then we reckoned how many Revolutions and Parts of a Revolution the Screw had made. And these added to the Arc terminated by the Point which the Plummet cut before the Observation, or

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subtracted from it, gave the Point of the Limb where the Plummets must have cut when the Star passed the Meridian. And last of all, we verified the Observation by replacing the Point under the Thread, as it had been before the passage of the Star. If the Micrometer marked still the same Revolution as it had marked before the Passage, or if the difference was but one or two Divisions, then the Observation was held as good. And we took the Mean between the two Numbers of the Micrometer, before and after the Observation, for the true Number which it marked when the Point of the Limb was exactly under the Thread. But if the difference of these two Numbers was more than two Divisions, we concluded that the Instrument must have been disturbed some how, and that the Observation was not to be depended upon.

THE two Stars which we observed with this Instrument past the one within less than $\frac{1}{2}$ Degree from the Zenith of *Kittis*, and the other not $\frac{1}{4}^{\circ}$ from that of *Tornea*. A Situation which might render us very secure as to any Errors arising from a wrong position of the Sector ; which in other cases,

if great care is not taken, may be very considerable. We knew that the misplacing it by several Minutes could have no sensible Effect upon our Observations; yet we placed it most exactly by a Meridian Line which we had drawn, and verified its position by the passage of some Stars whose heights we had taken.

II.

Observations of the Star δ of the Dragon made with the Sector upon Kittis, for determining the Amplitude of the Arc of the Meridian.

The 4th of October, 1736.

BEFORE the Observation of the passage of the Star in the Meridian, the Thread of the Plummets having been placed upon the point of the Limb marked $2^{\circ} 37' 30''$ of the upper Division, which we always made use of, the Micrometer marked

Revol.

24 10,7 parts,
whereof
44 go to
a Revol.

IN the time of Observation, that is, when the Star was passing the Meridian, the Micrometer marked . .

22 30,9

K

AFTER

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AFTER the Observation
the same Point $2^{\circ}.37'.30''$.
being replaced under the
Thread, the Micrometer mar-
ked Rev. part.
24 12,5

THE Mean of what the
Micrometer marked before
and after the Passage is . . 24 11,6

AND subtracting 22 30,9

RESTS, in parts of the
Micrometer, the Arc between
the point $2^{\circ}.37'.30''$. and
that where the Thread had
cut when the Star was in the
Meridian, viz. 1 24,7

5 Oct. { Before the Observ. . . 24 13,3
 { In the time of Observ. 22 31,4
 { After 24 15,3

24 14,3

22 31,4

Difference 1 26,9

6 Oct.

measured at the Polar Circle. 131

		Revol.	part.
6 October	{ Before the Observ.	24	9,8
	{ In the time of Observ.	22	28,2
	{ After	24	9,8
		24	9,8
		22	28,2
Difference		1	25,6
8 October	{ Before the Observ.	18	1,0
	{ In the time of Observ.	16	16,7
	{ After	17	43,0
		18	0
		16	16,7
Difference		1	27,3
10 Octob.	{ Before the Observ.	17	33,0
	{ In the time of Observ.	16	8,3
	{ After	17	33,1
		17	33,0
		16	8,3
Difference		1	24,7

THESE Observations were made by Day-light, without artificially illuminating the Focus of the Telescope:

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III.
*Observations of the same Star made at
 Tornea.*

1736.

THE Thread of the Plummet cutting
 the Point of the Limb marked $1^{\circ} 37' 30''$
 of the upper Division;

The Micrometer marked,

	Rev. parts.
Before the Observ. . . .	17 39,5
1 Nov. } In the time of Observ. .	19 36,3
After	17 40,5

Before the Observ. . . .	17 40,0
In the time of Observ. .	19 36,3

Difference 1 40,3

Before the Observ. . . .	18 13,1
2 Nov. } In the time of Observ. .	20 8,8
After	18 12,0

18 12,5
20 8,8

Difference 1 40,3

3 Nov.

measured at the Polar Circle 133

		Rev. parts.
3 Nov.	{ Before the Observ. . . .	18 37,0
	{ In the time of Observ. . .	20 33,3
	{ After	18 35,0
		18 36,0
		20 33,3
	Difference	1 41,3
4 Nov.	{ Before the Observ. . . .	18 32,2
	{ In the time of Observ. . .	20 28,4
	{ After	18 31,0
		18 31,6
		20 28,4
	Difference	1 40,8
5 Nov.	{ Before the Observ. . . .	12 24,4
	{ In the time of Observ. . .	14 20,5
	{ After	12 24,0
		12 24,2
		14 20,5
	Difference	1 40,3

THESE Observations were likewise made by Day-light.



C H A P. VI.

Calculation of the Arc of the Meridian which we had observed.

The Observations upon Kittis give	Rev. parts.
	I 24,7
	I 26,9
	I 25,6
	I 27,3
	I 24,7
Whose Mean is	I 25,8

The Observations at Tornea give	I 40,3
	I 40,3
	I 41,3
	I 40,8
	I 40,3
Whose Mean is	I 40,6

WE have then for the
 Arc of the Limb which
 the Thread cut as the Star
 passed the Merid. at Kittis 2 37 30—Rev. parts.
I 25,8

AND for the like Arc
 at Tornea I 37 30 + I 40,6
WHOSE

WHOSE difference
is that of the Star's di-
stance from the Zeniths
of *Kittis* and *Tornea*, viz.

$$\begin{array}{r} \text{Rev. parts.} \\ 1^{\circ} 0' 0'' - 3^{\circ} 22,4 \end{array}$$

TO reduce the Revo-
lutions and Parts of the
Micrometer into Minutes
and Seconds, it is to be
noticed (*vid. infra*) that

$$15' = 20 \text{ Rev. } 23,5 \text{ R. P.}$$

$$\text{Parts, whence } \dots 3^{\circ} 22,4 = 2^{\circ} 33,8$$

$$\text{Which taken from } \dots \begin{array}{r} 1^{\circ} 0' 0'' \\ \hline \end{array}$$

$$\text{give the Arc observed } \dots \begin{array}{r} 0^{\circ} 57' 26,2 \end{array}$$

FURTHER, by the
Construction of the Sec-
tor, the Chord of $5^{\circ} \frac{1}{2}$,
which is 10,625 Inches
English, is too little for
the Radius, which is
110,75 by 0,002; that is,
by $3'' \frac{3}{4}$; which $3'' \frac{3}{4}$ upon
 $5^{\circ} \frac{1}{2}$ give for $57^{\circ} \frac{1}{2}$ the

K 4

pro-

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proportional part to be
 subtracted, *P. A. R. T.* . . . 0,65
 leaving for the Arc ob-
 served, . . . 57 25,55

+++++

C H A P. I.

*Verification of the Horizontal Angles
 by their Sum*



15.0	58	118	<i>C K Y</i>
32.0	42	43	<i>H K C</i>
47.7	41	9	<i>P A R T</i>
23.3	11	27	<i>H V X</i>
7.3	22	93	<i>P V H</i>
4.3	23	21	<i>G V P</i>
25.7	14	49	<i>P O N</i>
24.3	24	47	<i>N P Q</i>
2.1	22	27	<i>H P N</i>
32.2	22	27	<i>N P H</i>

37 exceeds
 37, what it should be if the Figure
 3



PART II.

Containing Verifications of the whole Work.



CHAP. I.

*Verification of the Horizontal Angles
by their Sum round the Heptagon.*

CTK	24	22	54,5
KCT	37	9	12,0
KCH	100	9	56,8
HCA	30	56	53,4
CAH	112	21	48,6
HAP	53	45	56,7
APH	31	19	55,5
HPN	37	22	2,1
NPQ	87	52	24,3
PQN	49	14	52,7
QNP	51	53	4,3
PNH	93	25	7,5
HNK	27	11	53,3
NKH	9	41	47,7
HKC	43	45	35,6
CKT	118	28	12,0

Fig. 1.

THEIR Sum 900 1 37, exceeds
by 1'. 37", what it should be if the Figure

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lay in a plane Surface, and if there was no Error in the Observations; it ought indeed to be a little more than 900, because of the Earth's Convexity.



CHAP. II.

Vertification of the Heptagon, made at Tornea.

Fig. 4. **T**HE Centre of the Quadrant of two foot Radius being placed in the Line passing through the *Spire* of the Church and the Signal of *Niwa*, we took the Angle which the horizontal Sun made with the Signal of *Niwa*, marking the time by a Clock which we had carried to the highest place of the Isle *Swentzar*, and whose Hour we compared several times, by means of Signals, to that of a well-adjusted Pendulum in the House where I lodged.

measured at the Polar Circle. 139

1737, the 24th of May at Night.

True Time.

At $9^{\text{h}} 55' 16''$ nCS , $13^{\circ} 36' 26''$ = THE Angle between
the Signal of *Niwa* and
the Centre of the Sun,
concluded from the Pas-
sage of his two Limbs by
the vertical Wire in the
Telescope.

SUPPOSING the Sun's Declination
to be $20^{\circ} 53' 29''.7$, and the Latitude of
the place of Observation $65^{\circ} 51' 0''$. RCS
is found = $28^{\circ} 55' 48''$, The Angle of
the Vertical of the Sun
with the Meridian Line
for the moment of Ob-
servation ; from which
subtracting nCS already
found ($13^{\circ} 36' 26''$), remains RCn or RTn
= $15^{\circ} 19' 22''$ for the Angle which the
Meridian Line forms
with a Line joining the
Spire of *Torneå* and the
Signal of *Niwa*.

1737;

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1737. the 25th of May, in the Morning.

THE Centre of the Quadrant placed in the direction of *Kakama* and the Spire of *Tornea*.

True Time.

Fig. 5. At $2^h 35^m 44^s$ THE Angle between the Signal of *Niwa* and the Centre of the rising Sun.

$CK. 19. 52. 34$ THE Angle observed at the same place between the Signals of *Niwa* and *Kakama*.

$KCS. 24. 14. 0\frac{1}{2}$ ANGLE between the Signal of *Kakama* and the Sun.

$RCS. 28. 32. 48$ THE Angle of the Vertical of the Sun, with the Meridian calculated for the Moment of Observation, the Sun's Declination being $20^{\circ} 55' 22''$.

KCR

measured at the Polar Circle. 141

KCR , or KTR ... $4^{\circ} 18' 47\frac{1}{2}''$ The Angle which the Meridian Line makes with a Line joining the Spire and the Signal of *Kakama*.

1737. the 25th of May, in the Morning.

The Quadrant being in the same Situation.

True Time.

At $29^{\circ} 38' 38''$... nCS ... $45^{\circ} 36' 34\frac{1}{2}''$
 nCK ... $19^{\circ} 52' 34''$

 KCS ... $25^{\circ} 44' 0\frac{1}{2}''$ The Sun's
 RCS ... $30^{\circ} 2' 25''$ Declin. being

 $29^{\circ} 55' 25''$.

KTR ... $4^{\circ} 18' 24\frac{1}{2}''$ The Angle which the Meridian Line makes with a Line joining the Spire of *Tornea* and the Signal of *Kakama*.

Reducing the Position of *Niwa*, given Fig. 4 from the former Observation, to that of *Ka-* and 5. *kama*, by the Angle nTK , which (pag. 105)

is $19^{\circ} 38' 17''$, 8, we shall have KTR
 $4^{\circ} 18' 56''$ for the Declination of *Kakama*.

And taking the Mean of these three Observations,

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$4^{\circ} 18' 24\frac{1}{2}$ } we have $4^{\circ} 18' 42''\frac{1}{2}$ for the De-
 $4 \ 18 \ 47\frac{1}{2}$ } cination of *Kakama* to the
 $4 \ 18 \ 56$ } East.

But we had found from the Calculation
 of the Triangles, this Angle to be $4^{\circ} 11' 53''$
 to which adding for the Conver-
 gence of the Meridians of *Tor-*
nea and *Kittis* (found pag. 122.) $0 \ 7 \ 24$
 We shall have *KTR* . . . = . . . $4 \ 19 \ 17$

By the three preceeding Ob-
 servations, it was $4 \ 18 \ 42\frac{1}{2}$
 the Difference being $0 \ 0 \ 34\frac{1}{2}$
 too small to be looked upon as any real De-
 viation of the Meridian Line : and accord-
 ingly we made no account of it ; the rather
 because the Figure's Position had been de-
 termined upon *Kittis* by a greater number
 of Observations.



CHAP.



CHAP. III.
*Verification of the Distance of Tornea
 from Kittis, by ten new Series of
 Triangles.*

I.

BY the Triangles TnK , nKC , CKH , Fig. 6.
 HCA , AHP , PHN , NPQ .

BEGINNING always from the Side
 AC , the Resolution of these Triangles gives
 for the Distance QM 54941 toises,
 Which differs from 54942,57
 found above (pag. 120.) by our
 first two Series of Triangles, by. . . . $1\frac{1}{2}$

II.

BY the Triangles TnK , KHn , nCH ,
 HCA , APH , HNP , PNQ ; $QM = 54936$ Fig. 7.
 Less than QM (pag. 120.) by $6\frac{1}{2}$

III.

BY the Triangles TnK , KnH , HnA , Fig. 8.
 ACH ,

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$ACH, HAP, PHN, NPQ; QM = 54942\frac{1}{2}$

The difference being insensible.

IV.

Fig. 9. BY the Triangles $TnK, KCH, HnC, CHA,$

$AHP, PHN, NPQ; QM = 54943\frac{1}{2}$

The difference being I

V.

Fig. 10. BY the Triangles $TnK, KnC, CnA,$

$ACH, HAP, PHN, NPQ; QM = 54925$

The difference being $17\frac{1}{2}$

VI.

Fig. 11. BY the Triangles $TnK, KnH, HAn, nCA,$

$AHP, PHN, NPQ; QM = 54915\frac{1}{2}$

The difference being 27

VII.

Fig. 12. BY the Triangles $TnK, KnC, CAn, nHK,$

$KHN, NHP, PNQ; QM = 54912$

The difference being $30\frac{1}{2}$

VIII.

Fig. 13. BY the Triangles $TnK, KcN, nAC, CHK,$

$HKN, NHP, PNQ; QM = 54906\frac{1}{2}$

The difference being 36

IX.

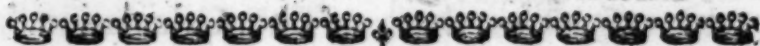
IX.

BY the Triangles TnC , CnA , AnH , Fig. 14.
 HAP, PHN, NPQ ; $QM = 54910$
 The difference being $32\frac{1}{2}$

X.

BY the Triangles TnC , CAn , nCK , KnH , Fig. 15.
 HKN, NHP, PNQ ; $QM = 54891\frac{1}{2}$ 54891
 The difference being $51\frac{1}{2}$.

THOUGH the differences arising from
 so many Series are none of them very con-
 siderable, yet we did not think fit to admit
 them into the Determination of the length
 of our Arc, but used two others which we
 judged preferable.



CHAP. IV.

*Another Verification of the Distance
 between Torneå and Kittis.*

ALTHOUGH from these ten Series, Fig. 16,
 it sufficiently appears that no mate-
 rial Error could have crept into our Obser-
 vations of the Triangles, seeing none of these

L

Com-

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Combinations, though some of them contain Triangles that might be rejected for the smallness of their Angles, produce any considerable Difference; yet we have added another Verification, which would take off all suspicion of that kind, even though we had observed no more than the Angles necessary for the first Series.

WE suppose as if we had in two of the Angles of every Triangle, mistaken by $20''$, and by $40''$ in the third; and that these Errors had always tended to shorten the Meridian Line QM . The small difference which rises from this Supposition proves the advantage we had from our Triangles being so few, and from the Position of the Base with respect to them. The Calculation is after this manner:

BEGINNING always from the Base Bb , and making the Angles Bba and bBa , less than BbA and bBA by $20''$, you find the Side aB instead of AB . Then making use of this Side aB , and making the Angles BaC , and aBc , less by $20''$ than BAC , ABC , you find the Point c instead of C , and the Side ac instead of AC .

FROM

measured at the Polar Circle. 147

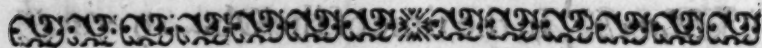
FROM *ac*, you find the Sides *ab* and *cb* instead of *AH* and *CH*, supposing the Angles *cab*, *acb*, less than *CAH*, *ACH* by 20" respectively. And proceeding still in the same manner in diminishing the Triangles, you come to have the Figure *qpnbackt* instead of *QPNHACKT*.

THEN supposing likewise an Error of 20" in the Position of the Meridian Line, that is, supposing *pqm* less by 20" than *PQM*, you find after the most exact Calculation *qm* less than *QM* by no more than 54 toises; a difference very inconsiderable to result from such a strange Supposition of bad Luck and unskilful Observation.



L 2

CHAP.



C H A P. V.

*Verification of the Amplitude of the
Arc of the Meridian.*

I.

*Observations of the Star α of the Dragon,
made at Torneå, in the same place where
we had observed δ .*

1737.

THE Plummets cutting the Point of the
upper division of the Limb marked
 $3^{\circ} 15'$, the Micrometer stood at

	Revol.	part.
17 March. { Before the Observ. . . .	19	32,7
{ In the time of the Obs. . .	16	42,0
{ After	19	34,0
	19	33,3
	16	42,0
Difference.	2	35,3

measured at the Polar Circle. 149

		Revol.	part.
18 March.	{ Before the Observ.	22	21,6
	{ In the time of the Obs.	19	30,4
	{ After	22	21,9
		22	21,7
		19	30,4
Difference		2	35,3

19 March.	{ Before the Observ.	21	21,0
	{ In the time of the Obs.	18	32,1
	{ After	21	21,3
		21	21,1
		18	32,1
Difference		2	33,0

II.

Observations of the same Star made upon Kittis, in the same place where we had observed δ .

1737.

THE Plummet cutting the Point of the upper Limb that is marked $4^{\circ} 15' 0''$.

The Micrometer stood at

4 April.	{ Before the Observ.	21	12,0
	{ In the time of the Obs.	14	43,0
	{ After	21	12,0
		21	12
		14	43
Difference		6	13,0

L 3

5

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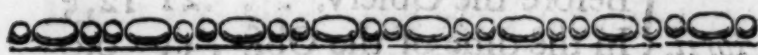
		Revol.	Part
5 April.	{ Before the Observ.	.21	12,5
	{ In the time of the Obs.	.15	6,6
	{ After	.21	12,2
		21	12,3
		15	0,0
	Difference	6	12,3
6 April.	{ Before the Observ.	.21	19,5
	{ In the time of the Obs.	.15	7,2
	{ After	.21	19,7
		21	19,6
		15	7,2
	Difference	6	12,4

THESE Observations both at *Torneå* and *Kittis*, were made by the Light of a Torch thrown by Reflection upon the Focus of the Telescope.



CHAP.

measured at the Polar Circle. 151



C H A P. VI.

Calculation of the observed Arc of the Meridian.

	Revol.	part.
THE Observations of Torneå give . .	2	35,3
	2	35,3
	2	33,0
And at a Mean . .	2	34,5

Those of Kittis give . . .	6	13,0
	6	12,3
	6	12,4
And at a Mean . .	6	12,6

WHENCE we have for the Arc of the Limb which the Plummet cut at the Star's Passage 3° 15' 0" — 2 34,5

And for the like Arc upon Kittis . . . 4 15 0 — 6 12,6

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The difference of which
two Arcs, that is the dif-
ference of the Star's di-
stances from the Zeniths
of *Torneå* and *Kittis* is

Revol. part.
1 0 0 3 22,1

But 3 Rev. 22,1 pt. 2 33,5
which subtracted from 1 0 0
leaves for the Arc observed 57 26,5
which the Correction on account
of the Chord of $5^{\circ}\frac{1}{2}$ its being
too small, viz. 0 0 0,65
reduces to 57 25,85

C H A P. VII.

Verifications of the Sector.

I.

Verification of the whole Arc of $5^{\circ}\frac{1}{2}$.

AT *Torneå*, the 4th of May, 1737, we
measured upon the Ice of the River a
distance of 380 toises, 1 f. 3 inches, 0 line: it
was measured twice over; and between the
first and second time, there was not the least
dif-

measured at the Polar Circle. 153

difference. At one Extremity of this distance was placed the Centre of the Instrument, which was laid horizontally upon two great Supports, in a Room we had chose for that purpose, by the River-side; at the other Extremity was raised a Post, with a *Mark* upon it; from whose Centre in a Line perpendicular to the first measured distance, which was to serve for a Radius, we laid out 36 T. 3 f. 6 in. $6\frac{1}{2}$ lin. for our Tangent, which was terminated at the Centre of a *Mark* fixed upon another Post. This formed upon the Ice a Sector of about 380 toises Radius, with which we were to compare ours.

FROM the Centre of the Instrument we had stretched a Silver Wire to a fixt Point, which by trials we had found to be altogether immoveable, so as when the Sector turned horizontally upon its Centre, the Wire only not touched its Limb.

THE Angle between the two Marks taken by five different Persons, exceeded $5^{\circ} 30'$, as follows:

Parts

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	Parts of the Microm.
1st. by . . .	6,5
2d. by . . .	8,3
3d. by . . .	7,0
4th. by . . .	7,9
5th. by . . .	6,8

Whereof the Mean is . . 7,3, or 7",3.

NOW according to the Construction of the Sector (pag. 135.) our Arc was too small by $3''\frac{3}{4}$:

whence from . . $5^{\circ}29'56'',25$
taking 7,3

rests the true Angle observed 5 29 48,95

And the same Angle is by Calcul. 5 29 50,00

Which shews the exquisite Construction of this Instrument, and what Accuracy may be expected from it. For this difference of 1" upon an Arc of $5^{\circ}\frac{1}{2}$, which might come from the Errors in observing, is altogether inconsiderable.

II.

*Verification of the two Degrees which we used
in determining the Amplitude.*

THE Sector remaining in the same horizontal Position, we extended from its Centre two small *Wires*, making with each other an Angle very nearly equal to 1° ; these Wires only not touched the Limb, and were fixed by two immoveable Pegs: over each of them we placed a Microscope, whose Focus was illuminated by the light of a Wax Candle, collected by a Lens; and as the Micrometer made the Telescope move, all the Points of the Limb passed successively in the Foci of the Microscopes.

IN this manner we compared with the fix'd Interval of the Threads, the two Degrees which we had made use of for the two Stars, making them pass under the threads by turns; and from five Observations made by different Persons, found that the Degree between $1^{\circ} 37' 30''$, and $2^{\circ} 37' 30''$, exceeded that between $3^{\circ} 15' 0''$, and $4^{\circ} 15' 0''$.

The

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The Excess was,			
By the 1st Observ.	.	.	0",6
2d	.	.	0",7
3d	.	.	0",8
4th	.	.	0",85
5th	.	.	1",8
			} 0",95

WHENCE at a Mean, the Arc used for determining the Amplitude by the Star δ was greater than that used for determining it by α , by 0",95.

THIS small difference of the two Degrees on the Limb, we ought to reckon upon quite otherwise than upon that of the preceding Article. That depended not only upon the Observation of the Point under the thread, but upon the Observation of an Object with the Telescope; whereas here we had only to place the point exactly under the thread; which, with a Microscope well lighted, may be performed to the utmost nicety.

III.

Verification of the Divisions of the Sector.

WE examined in the same manner every division of the Limb from $15'$ to $15'$; and have

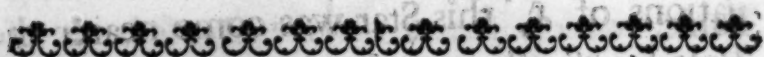
measured at the Polar Circle. 157

have marked the result in the following Table, which shews the Exactness both of the Divisions and of the Micrometer.

	according to us.		accor. to Mr. Graham.	
	Revol.	part.	part.	
From 0 15 to 0 30	20	23,2	22,75	
0 30 to 0 45		22,2	22,25	
0 45 to 1 00		23,7	23,5	
1 00 to 1 15		23,4	23,75	
1 15 to 1 30		24,3	24,5	
1 30 to 1 45		23,2	23,5	
1 45 to 2 00		23,8	24,5	
2 00 to 2 15		23,4	23,875	
2 15 to 2 30		23,1	23,5	
2 30 to 2 45		23,6	24,125	
2 45 to 3 00		23,3	23,5	
3 00 to 3 15		24,3	24,375	
3 15 to 3 30		24,0	24,0	
3 30 to 3 45		23,1	23,25	
3 45 to 4 00		24,0	24,125	
4 00 to 4 15		23,4	24,125	
4 15 to 4 30		22,9	23,75	
4 30 to 4 45		23,3	23,5	
4 45 to 5 00		22,9	22,75	
5 00 to 5 15		23,6	24,25	
5 15 to 5 30		23,0	23,625	
5 30 to 5 45		22,1	22,5	

The Mean gives 15' = 20R. 23,3p. 23,6p.

CHAP.



C H A P. VIII.

Determination of the Degree of the Meridian which cuts the Polar Circle.

I.

Determination of the Amplitude of the Arc of the Meridian, terminated by the Parallel Circles which pass through Kittis and Tornea.

THE Amplitude of the Arc of the Meridian as determined by the Star δ , was by Observation (p. 136.) . . $57^{\circ} 25' 55''$.

AND the same Amplitude as determined by α , was by Observation . . . $57^{\circ} 25' 85''$.

TO find the true Amplitude which the one and the other of these Stars gives, we must correct the Arcs as follows :

FOR THE STAR δ .

BY the Precession of the Equinoxes from the 6th of *October* to the 3d of *November*, which

measured at the Polar Circle. 159

which we take for the Interval of the Observations of δ , this Star was come nearer the Pole by $0'',48$; and the Star having been to the North of *Kittis*

from the Arc observed	57' 25'',55
subtracting this quantity	0,48
there will remain the <i>Amplitude</i>	
<i>corrected for the Precession</i> , viz. . .	<u>57 25,07</u>

BY the Aberration of the Star's Light in the same Interval, it was seen farther from the Pole by 1,83
 which added, gives for the *Amplitude corrected for both the Precession and Aberration* 57 26,9

FOR THE STAR α .

BY the Precession of the Equinoxes from the 18th of *March* to the 5th of *April*, the Interval of the Observations of α , this Star was farther from the Pole by $0'',85$; and having been seen to the South of *Torneâ*, from the Arc observed (p. 152.) viz. . . 57' 25'',85
 subtracting 0,85
 we have for the *Amplitude corrected for the Precession* 57 25,00

BY

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BY the Aberration of this Star's light in the same time, it appeared nearer the Pole by 5",35

which added, gives for the Amplitude as determined by α , corrected both for the Precession and the Aberration 57 30,35

II.

A more exact Determination of the same.

Mr. Bradley having been pleased to send me his last Discoveries upon the Motion of the fixt Stars, as likewise Corrections of the two Arcs determined by δ and α , not only for the *Precession* of the Equinoxes and *Aberration* of Light; but for that *third Motion* mentioned above; I shall here, for the greater accuracy, apply his Corrections as they were sent me, though they do not sensibly differ from those just now made:

To the Arc observed by δ (p. 136.) 57' 25",55
add 0 1,38

And you have the Amplitude by δ
corrected for all the Motions, viz. . 57 26,93

To

measured at the Polar Circle. 161

To the Arc observed by α (p. 152.) $57^{\circ} 25' 85''$
add $0^{\circ} 4' 57''$
and you have the *Amplitude* by α ,
corrected for all the Motions . . . $57^{\circ} 30' 42''$

THOUGH the difference between these two *Amplitudes* is no more than $3''.49$, it appears, from pag. 156, that it is really but $2''.54$: and it would not amount even to $2''$, if only the best of the Observations were used; these, where the Micrometer after the Star had past the Meridian, upon replacing the Point under the thread, stood at within $1''$ or less of what it had mark'd before. This difference is so small, that there is no doubt left of the Accuracy of the Operations.

I make no allowance for Refraction; for if there is any at all so near the Zenith, it must be imperceptible, and cannot effect the present Case.

III.

*Determination of the Degree of the Meridian
which cuts the Polar Circle.*

WE shall then take for the true *Amplitude* of the Arc of the Meridian between the

M

Paral-

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Parallels of *Kittis* and *Tornea*, $57^{\circ} 28'' 67$ being a Mean betwixt the two foregoing. And this Amplitude, compared with the length of the Arc $q\mu$, which (page 123.) is 55023,47 Toises, gives for the length of the Degree of the Meridian which cuts the Polar Circle 57437,9 Toises.

IV.

Remark upon the Degree measured by M. Picard.

THIS Degree is longer by 377,9 than that which passes commonly for the Mean Degree of *France*, rated by M. Picard at 57060 Toises. But if M. Picard's Degree is corrected by making the proper Allowances, first for the *Aberration* of Light of the Star δ in *Cassiopeia's Knee*, by which he determined his Amplitude, taking for the middle times of his Observations the 15th of *September*, and the 15th of *October*, there will be, on this account, $8''\frac{1}{2}$ to be added to the Amplitude of the Arc between *Malvoisine* and *Amiens*. And if there is further added $1''\frac{1}{2}$ for the *Precession* of the Equinoxes, and $1''\frac{1}{2}$ for the *Refraction*, all which he had neglected, his Amplitude will become

1° .

measured at the Polar Circle. 163

$1^{\circ}.23'.6''\frac{1}{2}$. And comparing it with his Arc of 78850 Toises, the Degree of the Meridian near *Paris* will be 56925,7 Toises, short of ours by 512,2.

IN fine, If Mr. *Bradley's* Theory is set aside, and the Stars are supposed to have no other Change of Declination but what arises from the Precession of the Equinoxes, our Amplitude by the Star δ (*page 159.*) would be $57'.25'',07$, and by the Star α (*ibid.*) $57'.25'',00$. Whence our Degree would be still longer than it is in Mr. *Bradley's* Hypothesis.

V.

CONCLUSION.

THE Degree of the Meridian which cuts the Polar Circle being longer than a Degree of the Meridian in France, the Earth is a Spheroid flattened towards the Poles.





C H A P. IX.

*A Method to determine the Figure of
the Earth from the Lengths of two
Degrees of the Meridian.*

IF the Length of two different Degrees of the Meridian is measured at two different places of known Latitudes, the Figure of the Earth may be determined: Of which Problem you have the following Solution; with a Formula expressing the Proportion of the Earth's Axis to the Diameter of the Equator.

Problem.

The Lengths and Latitudes of two Degrees of the Meridian being given, to find the Figure of the Earth.

Fig. 17. Considering the Earth as a Solid generated by the Revolution of an *Ellipse* upon its Axis, from which it very little differs, let the Ellipse PAp represent a Meridian, whose Axis is Pp , and the Diameter of the Equator

Equator Aa . Let Ee , Ff , be two Degrees of this Ellipse, or two little Arcs of the same Amplitude. The Perpendiculars to the Ellipse at their Extremities will meet at points G and H , making the Angles at G and H equal. And the Latitudes of these two Arcs, or the Angles EKA , FLA are given.

LET CP be to CA as m to 1; $CM = x$, $EM = y$; the Sine of the Angle EKA , that is the Sine of the Latitude of the point E , $= f$: The Sine of FLA , or of the Latitude of F , $= s$, and the Radius 1. Put likewise the Arcs $Ee = E$, and $Ff = F$.

BY the Property of the Ellipse $y = m \times \sqrt{1 - x^2}$; $EK = m \times \sqrt{1 - x^2} + m^2 x^2$; and the Radius of Curvature $EG = \frac{1}{m} \times 1 - x^2 + m^2 x^2 \bigg| \frac{3}{2}$ and the Expressions of FL and FH are the same for their correspondent x 's. Now the Sine of EKA , to the Radius 1, being f , $1 : f :: m \sqrt{1 - x^2} + m^2 x^2 : m \sqrt{1 - x^2}$, that is $x^2 = \frac{1 - ff}{1 - ff + m^2 f^2}$. Substituting this Value of x^2 in the Expressions of EG and

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FH , we have $EG = \frac{m^2}{1 - s^2 + m^2 s^2}^{\frac{3}{2}}$

and $FH = \frac{m^2}{1 - s^2 + m^2 s^2}^{\frac{3}{2}}$ And seeing the Arcs Ee , and Ff are of the same Amplitude, that is, seeing the Angles G and H are equal, $E : F :: \frac{m^2}{1 - s^2 + m^2 s^2}^{\frac{3}{2}}$

$\frac{m^2}{1 - s^2 + m^2 s^2}^{\frac{3}{2}}$ that is,

$E \times 1 + m^2 - 1 \times s^2^{\frac{3}{2}} =$

$F \times 1 + m^2 - 1 \times s^2^{\frac{3}{2}}$ Or, by extracting the Root,

$E \times 1 + \frac{3}{2} \times m^2 - 1 \times s^2 + \frac{3}{8} \times m^2 - 1^2 \times s^4 + \&c.$

$= F \times 1 + \frac{3}{2} \times m^2 - 1 \times s^2 + \frac{3}{8} \times m^2 - 1^2 \times s^4 + \&c.$

BUT the Spheroid of the Earth being very little different from a Sphere, the quantity $m^2 - 1$ is small, and the Terms multiplied by its Square and its higher Powers may

be neglected. Whence $E \times 1 + \frac{3}{2} \times m^2 - 1 \times s^2$

$= F \times 1 + \frac{3}{2} \times m^2 - 1 \times s^2$ that is,

$2E + 3 \times m^2 - 1 \times E s^2 =$

measured at the Polar Circle. 167.

$$2F + 3 \times \frac{m^2}{1} - 1 \times F s^2. \text{ Or } 1 - m^2$$

$$= \frac{2 \times E - F}{3 \times E f^2 - F s^2} \text{ Or putting } D \text{ for}$$

the difference between the Semi-axe and the Semi-diameter of the Equator, it is $D =$

$$\frac{E - F}{3 \times E f^2 - F s^2} \text{ or } D = \frac{E - F}{3 E \times f^2 - s^2}$$

Whence the Species of the Spheroid may be easily determined, and a Table calculated of the Lengths of a Degree for every Latitude.

Coroll. IF one of the Degrees is taken at the Equator, the Equation is changed into

$$D = \frac{E - F}{3 E f^2} \text{ And if the other Degree is taken at the Pole, it is } D = \frac{E - F}{3 E}$$

$$D = \frac{E - F}{3 E}$$

Whence it follows, That the Semi-Diameter of the Equator is to thrice the last Degree of Latitude, as the difference between the Semi-Diameter of the Equator and the Semi-Axis is to the difference between the first and the last Degree of Latitude.

OBSERVATIONS

Made at the Polar Circle.

BOOK II.

Containing Astronomical Observations for determining the Height of the Pole at Torneå, the Refraction, and the Longitude.

CHAPTER I.

Observations of Arcturus, and of the Pole-Star, at Torneå and at Paris.

I.

Observations of Arcturus, and the Pole-Star, at Torneå.

WE observed the distances of the Pole-Star, and of *Arcturus* from the Zenith, at *Torneå* and *Paris*, in order to discover if, at the height of these Stars, the Refraction at *Torneå* was sensibly different from

Astronomical Observations, &c. 169

from what it is at *Paris* ; as the Observations of *Bilberg* at *Torneå*, and of the *Hollanders* in *Nova Zembla* gave ground to think.

WE had chose these two Stars, because the Arc of the Meridian terminated by their Parallels, was, at *Torneå*, nearly of the same height as at *Paris*, only in an opposite Situation. Whence, if the Refraction was greater at *Torneå*, this Arc must there appear shorter than at *Paris*.

BUT it is found by Observation to be very near of the same quantity at both these places. The little difference there was, made rather for lessening the Refraction at *Torneå* ; but this we ascribe to the Errors of the Observations, which were not of Authority enough to establish an Inequality of Refraction, at that height.

FOLLOW the Observations of these two Stars, made at *Torneå* with a Quadrant of three foot Radius, and at *Paris* with one of $2\frac{1}{2}$; both well verified by back Observations.

Distance

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Distance of the Pole-Star from the Zenith of Torneå.

Observed in *Novem.* and *Decem.* 1736. Reduced for 1737.

	[°]	[']	["]	[°]	[']	["]
27 Novemb. . .	22	2	51	22	3	11
29 Novemb. . .	22	2	40	22	3	0
1 Decemb. . .	22	2	43	22	3	3

Whence, at a Mean, the distance of the Pole-Star from the Zenith of *Torneå*, in the beginning of *December* 1737,

22	3	5
----	---	---

Distance of Arcturus from the Zenith of Torneå.

	[°]	[']	["]	[°]	[']	["]
1736						
26 Novemb. . .	45	15	49	45	16	6
1 Decemb. . .	45	16	4	45	16	21
3 Decemb. . .	45	15	43	45	16	0
9 Decemb. . .	45	15	52½	45	16	9½

Whence

Whence at a Mean, the distance of *Arcturus* from the Zenith of *Torneå* was, in the beginning of *December* 1737, 45 16 9

Which added to the distance of the Zenith from the Pole-Star 22 3 5

Gives for the Arc of the Meridian terminated by the Parallels of these two Stars, as observed at *Torneå*, 67.19 14

II.

Observations of the same Stars at Paris.

Distance of the Pole-Star from the Zenith of Paris,

Observed in *Novemb.* and *Decemb.* 1737.

8 Novemb.		39	2	19 $\frac{1}{2}$
9 Novemb.		39	2	22
5 Decemb.		39	2	30
8 Decemb.		39	2	33
14 Decemb.		39	2	34

Whence

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Whence at a Mean, the distance of the Pole-Star from the Zenith of *Paris* was, in the beginning of *December*

1737, 39° 2' 18"

Distance of Arcturus from the Zenith of Paris.

29 October 1737 28° 16' 30"

8 November 28 16 32

16 December 28 16 44

24 December 28 16 43

Whence, at a Mean, the distance of *Arcturus* from the Zenith of *Paris* was, in the beginning of *December* 1737, 28 16 37

Which added to the distance of the Zenith from the Pole-Star 39 2 28

Gives the Arc of the Meridian terminated by the Parallels of these two Stars, as observed at *Paris*, 67 19 5

III. *The*

Whence at a Mean, the di-

III. stance of the Pole from

The same repeated, upon Observations of the Pole-Star in the lowermost point of its Circle.

Distances of the Pole-Star from the Zenith of Torneå.

Observed in Nov. and Decemb. 1736. Reduced for 1737.

26 Novemb. . . .	26	14	37	26	14	17
27 Novemb. . . .	26	14	37	26	14	17
1 Decemb. . . .	26	14	36	26	14	16

Whence at a Mean, the distance of the Pole-Star from the Zenith of Torneå was, in the beginning of December

1737, 26 14 17

The distance of *Arcturus* (page 171.) was 45 16 9

Whence the Arc of the Meridian terminated by the Parallels of these two Stars, as observed at Torneå, is 71 30 26

IV. Di-

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IV.

Distances of the Pole-Star from the Zenith of Paris.

Observed in *Novem.* and *Decem.* 1737.

2 Decemb.	43° 13' 42"
3 Decemb.	43 13 41
9 Decemb.	43 13 42
14 Decemb.	43 13 47
19 Decemb.	43 13 45

Whence at a Mean, the distance of the Pole-Star from the Zenith of *Paris* was, in the beginning of *December*

1737, 43 13 43

The distance of *Arcturus* (*p.* 172.)

28 16 37

Whence the Arc of the Meridian terminated by the Parallels of these two Stars as observed at *Paris*, is

71 30 20

V.

FROM which Observations it appears, that at the height of these Stars, the Refractions

fractions at *Torneå* and at *Paris* are not sensibly different.

BUT, independent of these Observations, we may first seek the height of the Pole at *Torneå*, supposing these Refractions to be equal, which at this height can cause no sensible Error; and then make use of the height of the Pole thus determined, to find the horizontal Refractions; which if they come out nearly the same as at *Paris*, we may thenceforth safely enough use the same Table of Refraction for the greatest Altitudes at *Torneå*.



C H A P. II.

Height of the Pole at Torneå.

I.

Height of the Pole, from Observations made with the Quadrant of three foot Radius.

IN the beginning of *December* 1736, the least distance of the Pole-Star from the

Zenith of *Torneå* was (page 170.) $22^{\circ} 2' 45''$
the greatest (page 173.) $26^{\circ} 14' 37''$

Their Sum . . . $48^{\circ} 17' 22''$

Whose half . . . $24^{\circ} 8' 41''$

is the distance of the Zenith of *Torneå* from the Pole, and its Compliment . . . $65^{\circ} 51' 19''$

will be the apparent height of the Pole. From which subtracting a Mean between the Refractions at *Paris*, as determined by Mr. *Cassini* and Mr. *de la Hire*, viz. . . $0^{\circ} 0' 29''$

there remains . . . $65^{\circ} 50' 50''$
for the height of the Pole at *Torneå*, that is for the southernmost point of the Arc which we measured.

II. *Height*

II.

Height of the Pole, from Observations made
in the same Place with a Quadrant of
two foot Radius.

The greatest distance of the Pole-Star from the Zenith. | The least distance of the Pole-Star from the Zenith.

At Tornea 1737.

6 Jan.	26 14 21	9 Jan.	22 3 2
7 Jan.	26 14 24	12 Jan.	22 2 57
		18 Jan.	22 2 54
		19 Jan.	22 3 0

This day the Qua-
drant had been ve-
rified by back-Ob-
servation. } 22 Jan. 22 2 57

The Means 26 14 22 $\frac{1}{2}$ 22 2 58

Sum of these distances 48 17 20

whose half 24 8 40

is the distance of the Zenith of

Tornea from the Pole, whose

Complement 65 51 20

is the apparent height of the

Pole; from which taking for the

Refraction 0 0 29

remains the height of the Pole at

Tornea 65 50 51

N

III. A

III.

A Remark.

ALTHOUGH these heights of the Pole in the two last Articles coincide, yet you may observe there is a difference of 14" in the distance of the Pole-Star from the Pole, as there marked. Which makes me suspect there have been some Errors in the Observations that have compensated each other. This might be partly caused too, by the Precession of the Equinoxes and the *Aberration* of Light, in the interval of the Observations.

WE may then take for the height of the Pole at *Torneå* $65^{\circ} 50' 50''$. exceeding what *Bilberg* found it to be by 8', and by 11' what he ought to have found it, if he had made the proper Allowances for the obliquity of the *Ecliptic*, the *Parallax*, and *Refraction*.

AND seeing his Observations gave him an Altitude of the Pole so wide of the Truth, we need not wonder that he fell into still greater Errors as to the *Refraction*; which

which has hitherto been imagined to be almost the double of what it is at *Paris*.

THE Amplitude of our Arc between *Torneå* and *Kittis* being (p. 162.) $57^{\circ} 28,7$
the height of the Pole upon *Kittis* will be $66^{\circ} 48' 18,7$
for which we shall take $66^{\circ} 48' 20$



CHAP. III.

Meridian Altitudes of the Sun.

I.

Meridian Altitudes of the upper Limb of the Sun, observed at Torneå, at the extremity of our Meridian Line, with a Quadrant of three foot Radius, 1736.

WE placed, in a little Observatory built on the River, the Instrument we had made use of at *Kittis* to determine the position of our Triangles with respect to the Meridian Line, (*vid.* p. 109.)

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THE Telescope of this Instrument moved about its Axis, exactly in the Plane of the Meridian ; and if it chanced to be put out of this position, we restored it by means of an Object placed at about half a League's distance in the Meridian Line. The Altitudes were taken in the Moment the Sun past the Centre of this Telescope.

26 November 1736	3 35 23
27 November	3 24 30
1 December	2 45 42
3 December	2 31 0
8 December	1 56 51

II.

Meridian Altitudes of the Upper Limb of the Sun observed in the same place, with a Quadrant of two foot Radius, 1737.

5 January 1737	2 9 32
7 January	2 24 33
9 January	2 37 26
12 January	3 4 26
13 January	3 15 23
19 January	3 21 29

ON

ON the 22d the Quadrant was verified by back-Observation, and afterwards used to take the horizontal Angles.

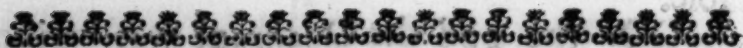
III.

Meridian Altitudes of the Sun's upper Limb at the vernal Equinox.

WE verified once more the Quadrant of three foot, and observed the following Meridian Altitudes of the upper Limb of the Sun.

15 March 1737	. . .	22° 26' 16"
16 March	. . .	22 50 12
17 March	. . .	23 13 50
18 March	. . .	23 37 9
21 March	. . .	24 47 11
22 March	. . .	24 11 35





C H A P. IV.

Determination of the Refractions.

THE following Calculation supposes the height of the Pole, as found p. 178.

THE finding the Refraction by the Meridian Altitudes of the Sun supposes likewise, to be given, the *Elevation of the Equator, the Obliquity of the Ecliptic, the Sun's Place, and his Parallax.*

I put the Elevation of the Equator 24 9 10
 the Obliquity of the *Ecliptic* 23 28 20
 the Parallax according to Mr. *Cassini*; and the Sun's place, from Mr. *de Louville's* Tables, reduced to the Meridian of *Tornea*, which we know to be nearly 1^h. 23' East of *Paris*. And an Error of a few Minutes can here be of no consequence, because, at the time of our Observations, the Sun's daily

at the Polar Circle. 183

daily Change of Declination is inconsiderable.

II.

The 1st of Decemb. 1736, at Noon.

The South Declination of the	..
Sun at <i>Tornea</i>	21 55 21
The Elevation of the Equator .	24 9 10
Whence the height of the Sun's	
Centre	2 13 49
The Parallax to be subtracted .	0 0 10
Leaves the true height of the	
Sun's Centre at <i>Tornea</i> .	2 13 39
The Sun's Semi-diameter to	
be added	0 16 19
Gives the true height of the	
Sun's upper Limb	2 29 58
But the same height was by	
Observation	2 45 42
Whence the Refraction at the	
apparent height of 2°. 46'. is	0 15 44

N 4

III. The

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III.

The 3^d of Decemb. 1736, at Noon.

The South Declination of the	•	'	"
Sun at <i>Torneå</i>	22	12	46
The Elevation of the Equator	24	9	10
Whence the height of the Sun's			
Centre	1	56	24
The Parallax to be subtracted	0	0	10
Leaves the true height of the			
Sun's Centre at <i>Torneå</i>	1	56	14
The Sun's Semi-diameter to be			
added	0	16	20
Gives the true height of the			
Sun's upper Limb	2	12	34
But the same height was by			
Observation	2	31	0
Whence the Refraction at the			
apparent height of 2°. 31'.	0	18	26

IV. *The*

IV.

The 8th of Decemb. 1736, at Noon.

The South Declination of the	
Sun at Tornea	22 48 33
The Elevation of the Equator .	24 9 10
Whence the height of the Sun's	
Centre	1 20 37
The Parallax to be subtracted .	0 0 10
Leaves the true height of the	
Sun's Centre at Tornea	1 20 27
The Sun's Semi-diameter to be	
added	0 16 21
Gives the true height of the	
Sun's upper Limb	1 36 48
But the same height was by	
Observation	1 56 51
Whence the Refraction at the	
apparent height of $1^{\circ} 57'$. .	0 20 3

V. The

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V.

The 5th of January 1737, at Noon.

The South Declination of the		°	'	"
Sun at <i>Torneå</i>	22	35	53	
The Elevation of the Equator	24	9	10	
Whence the height of the Sun's				
Centre	1	33	17	
The Parallax to be subtracted	0	0	10	
Leaves the true height of the				
Sun's Centre at <i>Torneå</i>	1	33	7	
The Sun's Semi-diameter to be				
added	0	16	22	
Gives the true height of the				
Sun's upper Limb	1	49	29	
But the same height was by				
Observation	2	9	32	
Whence the Refraction at the				
apparent height of $2^{\circ} 9\frac{1}{2}'$	0	20	3	

VI.

WE have here chose the least Altitudes of the Sun, to calculate the Refractions and compare them with those at *Paris* for the

the same Altitudes, 'according to Mess^{rs} Cassini and de la Hire; and do not find those of *Torneå* so much different as to infer an Inequality of Refraction at *Torneå*, and at *Paris*.

AND if the Refractions are very much less at the Equator than at *Paris*, we may at least be very sure that their Increase from *Paris* to the *Polar Circle* is very inconsiderable; contrary to what has been hitherto thought, that they were twice as great at *Torneå* as at *Paris*.



C H A P. V.

*Determination of the Refractions upon
Kittis by Venus Inocidua.*

WE have farther, upon this Subject, some singular enough Observations upon the Planet *Venus*, which for two Months together appeared always above our Horizon. We observed her first at *Kittis* with the Quadrant of 3 f. Radius, well verified.

Meridian Altitudes of Venus upon Kittis.

To the North.

Corrected by the Parallax.

5th April 1737, in the Morn.	0 58 6"	0 58 21"
6th	1 11 44	1 11 59
7th	1 25 5	1 25 20

To the South.

Corrected by the Refraction and Parallax.

6th April 1737, in the Even.	47 17 54	47 17 3
7th	47 32 45	47 31 54
Diurnal Motion in Declination		14 51

WE

WE corrected the Altitudes of *Venus*, that were observed to the South, by both Refraction and Parallax, putting 15" for her horizontal Parallax in the distance she then was from the Earth.

II.

Calculation of the Refractions upon Kittis, from the Observations of Venus.

Height of the Pole upon *Kittis*

(p. 179.) 66° 48' 20"

Elevation of the Equator . . . 23 11 40

Meridian Altitude of *Venus*, the
6th of *April* in the Evening . . 47 17 3

North Declination of *Venus* . . 24 5 23

Distance of *Venus* from the Pole,
the 6th of *April* in the Evening 65 54 37

Meridian Altitude of *Venus*, the
7th of *April* in the Evening . . 47 31 54

North Declination of *Venus* . . 24 20 14

Distance of *Venus* from the Pole,
7th *April* in the Evening . . . 65 39 46

Whence the Distance of *Venus*
from the Pole, when she past the
Meridian to the North, on the

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7th of *April* in the Morning, was $65^{\circ} 47' 11\frac{1}{2}''$

And consequently her true Altitude $1^{\circ} 1' 8\frac{1}{2}''$

The Meridian Altitude of *Venus*, the 7th of *April* in the Morning, as observed and corrected by the Parallax, was $1^{\circ} 25' 20''$

Whence the Refraction at the Altitude $1^{\circ} 25'$ is $24' 11\frac{1}{2}''$



C H A P. VI.

The like Operations at Torneå.

I.

WE continued at *Torneå* our Observations of this Planet, having for that purpose verified the Quadrant of 2 foot.

Meridian Altitudes of Venus.

Corrected by the Refraction and Parallax.

To the South.

	0	'	"	0	'	"
28th <i>April</i> 1737, in the Even.	51	36	3	51	35	20
29th	51	38	50	51	38	7
30th	51	41	47	51	41	4

To

at the Polar Circle. 191

To the North.

Corrected by the Parallax.

30th of April	0 3 34 58	0 3 35 14
1st of May	3 38 5	3 38 21

II.

Calculation of the Refractions at Tornea, by the Observations of Venus.

Elevation of the Equator at Tornea 24 9 10

Meridian Altitude of ♀ the 28th of April 51 35 20

North Declination of ♀ 27 26 10

Distance of ♀ from the Pole, 28th of April 62 33 50

Meridian Altitude of ♀, the 29th of April 51 38 7

North Declination of ♀ 27 28 57

Distance of ♀ from the Pole 62 31 3

Diurnal Motion in Declination, from the 28th to 29th April 0 2 47

Meridian Altitude of ♀, the 30th of April 51 41 4

North Decl. of ♀ 27 31 54

Distance of ♀ from the Pole 62 28 6

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Diurnal Motion of Declination,
from the 29th to 30th *April* . . . 0 2 57

The Mean of these diurnal Mo-
tions 0 2 52

Whereof one half for 12 hours is 0 1 26

Distance of *Venus* from the Pole,
the 30th of *April*, P.M. . . . 62 28 6

Whence the Distance of *Venus*
from the Pole, when she past the
Meridian, the 30th of *April* in
the Morning 62 29 32

and on the 1st of *May* in the
Morning 62 26 40

Whence her { 30th *April*, A.M. 3 21 18

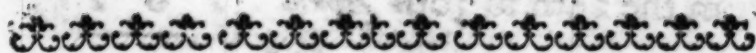
true Height { 1st of *May*, A.M. 3 24 10

Merid. Alt. {
of ♀, as ob- { 30th *April*, A.M. 3 35 14

served and {
corrected by { 1st of *May*, A.M. 3 38 21
the Parallax. { 3 38 21

Whence the Refract. { 3° 35' . . . 0 13 56
at the Altitude . . { 3 38 . . . 0 14 11

CHAP.



C H A P. VII.

Concerning the Longitude of Tornea.

I.

WE could make no use of *Jupiter's Satellites*, because at the time we might have observed him, he was too near the Horizon, and always hid in Vapour.

WE endeavoured therefore to determine this Longitude by some other Observations; from which, as here set down, it may be found out, provided correspondent Observations have been made in any Place, whose Longitude is known.

Eclipses of fix'd Stars, by the Moon.

The 12th of December, 1736, P. M.

Time by the Clock.

^h 11 15 4	<i>Aldebaran</i>	} Transits observed with the Telescope moveable on an Axis, in the Plane of the Meridian.
11 56 2	<i>Rigel . . .</i>	
11 46 12 $\frac{1}{2}$	an Occultation of the Star	

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Star μ in the *Linum* of *Pisces*, which gives $11^h 29' 58''$ true Time.

AS the Sun rarely appeared, being at Noon less than a Degree above the Horizon, we calculated the Hour by comparing his *Right Ascension* with that of the Stars *Aldebaran* and *Rigel*.

The 12th of January, 1737, P. M.

True Time.

$6^h 4' 30''$ an Occultation of γ of *Taurus*.

$10^h 57' 58''$ an Occultation of the Northernmost of the two Stars of *Taurus*, called δ .

The 13th of January, 1737, A. M.

$3^h 14' 20''$ an Emerfion of *Aldebaran*.

WE found the Hour by Observations of the Sun in the Meridian, taken the 12th and 13th of *January*.

The 11th of March, 1737, P. M.

True Time.

$7^h 35' 9''$ an Occultation of λ in *Gemini*.

II.

A Horizontal Eclipse of the Moon.

The 16th of March, 1737, P. M.

True Time.	Quantity of the Eclipse.
6 ^h 23 55	5 dig. 0
25 30	<i>Promontorium acutum</i> is discover'd.
28 0	4 56
28 30	The Shadow touches the <i>Mare humorum</i> .
35 0	4 0
39 30	3 29
40 20	The Shadow touches <i>Langrenus</i> .
43 40	<i>Tycho</i> half discovered.
47 0	<i>Mare Nectaris</i> out of the Shadow.
47 30	2 37
49 15	2 21
51 45	2 7
53 35	1 56
7 2 10	End of the Eclipse, with a Telescope of 7 foot.
2 35	} End of the Eclipse, with 2 Reflecting Telescopes of 15 Inches.
2 50	

III.

WE have one Observation more of a Star eclipsed by the *Moon*, taken upon one of our Mountains.

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The 2d of August, 1736, A. M. upon Pullingi.

A little before the Observation, we compared two exceeding good Watches.

$5^h 36' 0'' \frac{1}{2}$ by the Watch R }
 $5^h 26' 15''$ by the Watch G } diff. $9' 44'' \frac{1}{2}$

At $5^h 46' 42''$ on the Watch R, an Immersion of *Aldebaran*, in the enlightned Disk of the Moon.

The Watches { $5^h 49' 0''$ R } differ. . . $9' 45''$
 compared. { $5^h 39' 15''$ G }

Heights of the upper Limb of the Sun in the East, with the Quadrant of 2 foot.

R... $5^h 59' 14''$ }
 G... $5^h 49' 22''$ } $16^{\circ} 20' 0''$

R... $6^h 4' 16'' \frac{1}{2}$ }
 G... $5^h 54' 30'' \frac{1}{2}$ } $16^{\circ} 50' 0''$

R... $6^h 9' 20''$ }
 G... $5^h 59' 32''$ } $17^{\circ} 20' 0''$

Meridian Altitudes of the upper Limb of the Sun.

The 1st of August . . . $41^{\circ} 35' 10''$
 2d . . . $41^{\circ} 20' 0''$

FROM

FROM these Observations we concluded, that the Immersion of *Aldebaran* happened at 5^h 45' 0", true Time.

To find the Longitude of *Torneå*, you may likewise make use of the Observations of the Sun at the Equinox, (p. 181.) We have in our Calculations put it at 1^h 23' East of *Paris*. It may be more accurately fixt when the correspondent Observations are got, and all of them compared together.



C H A P. VIII.

The Declination of the Magnetic Needle.

THIS Observation we made with a Brass Compass, 10 Inches in diameter, by looking through its Sights at an Object placed in the Meridian Line of our little Observatory upon the River. And the Mean of our Observations with four different

Q 3

Needles,

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Needles, gave us for the Declination at *Tor-*
nea in the Year 1737. $5^{\circ} 5'$ West.

Mr. *Bilberg*, in 1695, had found it 7° ,
West likewise.

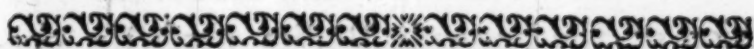


BOOK



BOOK III.

The Measure of Gravitation at the Polar Circle.



CHAP. I.

Of Gravitation in general.

WHATEVER be the Cause of Gravitation, we may conceive it as a Force inherent in Bodies, whereby they are animated, as it were, and urged to fall towards the Earth ; and upon comparing the Effects of this Force, when it makes a Stone fall to the ground, with what it must be to keep the Moon in her Orbit, we shall find by Calculation, that the Gravitation which acts here upon the Earth, extends to the Region of the Moon, and regulates her Motion. As the Power which makes Bodies fall downwards, likewise retains the Moon in
O 4 her

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her Orbit, as she circles round the Earth; we are led by Analogy to think, that every Planet, and the Sun himself, has each its Gravitation, producing the like effects: and that what the Moon is to the Earth, that is the Earth it self, and every other Planet, to the Sun. A Gravitation towards the Sun may possibly be the Power that keeps them in their Orbits. And indeed the Motion of the heavenly Bodies perfectly corresponds to this universal Law. Such are the Effects of Gravitation in the Heavens.

IT would be going too far to mention all its Effects here on Earth. It is This that presides almost in every Physical Operation; and while the greatest part of Machines are contrived to overcome it, it is the Agent that gives motion to the rest.

IF we are ignorant of the Cause of *Gravitation*, as probably we must ever be; we know however one of its most essential Properties; that it is diffused through all Bodies in proportion to their quantities of Matter; each Particle of the Body sharing an equal portion of whatever Cause it is that makes it fall.

HERE

HERE we must carefully distinguish between the *Gravitation* of a Body, and its *Weight*. *Gravitation* is that Force, conceived as distinct from the Body, which animates and urges every one of its parts to fall; whence it happens, that, abstracting from the resistance which the Air makes to falling Bodies, a great Body falls just as soon, and no sooner, than the smallest of its parts, if it were detach'd from it, and fell alone from the same height.

GRAVITATION in a great Body is no greater than in a small. The Case is different as to *Weight*; *that* depends not only upon *Gravitation*, but likewise upon the quantity of Matter of the Body. The *Weight* increases in proportion to the Body; it is the product of the *Gravitation* and the quantity of Matter.

BUT is *Gravitation* the same all the Earth over? Will it every where make Bodies fall from the same height in the same time? A very little attention serves to shew, that this Question is not to be resolved by weighing one and the same Body in different places.

In

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In the place you carry it to, Gravitation will equally affect the Body it self and the Weights you compare it with: And that which weighed a Pound at *Paris*, will weigh the same any where else.

BUT a Pendulum that swings freely, whether suspended by a Thread, or by an inflexible Rod, moves with a determinate Velocity which depends on the length of the Pendulum, and the Force of Gravitation together. And if trial is made with such a Pendulum, keeping its length exactly the same in the different places, there can no difference happen in the velocity of its Vibrations, but from a difference of Gravitation. For the different Density or Elasticity of the Air will here produce no sensible effect; especially if the degree of Heat in the Countries where the Experiments are made is the same, which is exactly enough known by a Thermometer. If, in the Country where the Pendulum should be carried, the Gravitation should be greater, its Vibrations would be quicker; and if it was less, they would be more slow. This last is that Phenomenon which was first taken notice of by Mr. *Richer*, in the Island of *Cayenne*; and one

one of the noblest Discoveries in Natural Philosophy it is. Bodies were found to weigh less at *Cayenne* than at *Paris*; and soon after a very probable Cause of this Phenomenon was assigned.

ALL Bodies that have a circular Motion make a continual Effort to recede from the Center. This Effort arises from a certain Force there is in Matter, whereby it endeavours to continue in its present State, whether of Rest or Motion. Now as a Body revolving in a Circle describes in every Instant a Particle of the Circumference, which may be considered as a Right Line, it must in every Instant be making an effort to go on in the direction of that Right Line; and from this Effort is produced what is called the Body's *Centrifugal Force*.

IF the Earth then revolves about its Axis, each of its Parts endeavours to recede from its Centre of Motion; and the greater the Circle is which the Part describes, that is, the nearer it is to the Equator, the greater will this Effort be; and as it tends to throw off Bodies from the Earth, that is, as its Direction is opposite to that of Gravitation, it must
destroy

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destroy some part of it; and so much the more, as the Body is near the Equator. If therefore the *Primitive Gravitation*, which I shall call *Gravity*, to distinguish it from Gravitation as diminished by the Centrifugal Force; if, I say, Gravity were absolutely equal every where, yet the actual Gravitation of a Body must be less towards the Equator, and increase towards the Poles; where at last it suffers no more any diminution from the Centrifugal Force, because the Poles are no wise affected by the Earth's Revolution round its Axis.

THIS Theory of Gravitation is extremely probable, and has been confirmed by all the Experiments that have been made near the Equator.

YET, before our Journey to the North, it was not perhaps absolutely sure that Gravitation was thus regularly diminished in going towards the Equator, although the Observations made in *America* all gave some diminution. The physical Cause of Gravitation being unknown, it might still be doubted whether the diminution observed was owing to the primitive Gravity its being

im-

impaired by the Centrifugal Force, or whether it might not have some particular Cause combined with the Centrifugal Force: it might even be questioned whether the primitive Gravity itself was not subject to regular, or perhaps irregular Variations. The rather, that some Experiments made by able enough Artists, seemed to give colour to these Suspicions. Mr. *Picard* had not found his Second-Pendulum longer in *Denmark* than at *Paris*, nor even longer than in the Southermost Parts of *France*.

IN short, hitherto the only Proof of this Diminution was from Experiments made, towards the Equator indeed, but in places too little distant from each other to found an unexceptionable Proof.

IT were to be wished that trial were made in the *East-Indies*, at the Latitudes of *Cayenne*, *S. Domingo*, and *Jamaica*, whether the diminution was there the same as in *America*. But nothing could be more proper for the decision of this important Point, and for Natural Philosophy in general, than the observing the Gravitation of Bodies in the most Northern Countries, especially after the

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the Doubts that M. *Picard's* Experiments in *Denmark* had raised.

LET it still be remembred what distinction I make between *Gravity* and *Gravitation*. *Gravity* is that Force whereby a Body would fall to the Earth, supposed at rest: *Gravitation* is the same Force, but diminished by the *Centrifugal*. 'Tis only this last, diminished, and confounded with the *Centrifugal*, which we can measure by our Experiments; but if we are well acquainted with it, we may come at last to distinguish what of the Primitive *Gravity* remains, and what has been destroyed by the *Centrifugal* Force.

HITHERTO this Subject has been enquired into with no other view than to determine the Figure of the Earth from the Equilibration of its parts. But the Theory of *Gravity* serves to much greater purposes than this Determination.

IF the Primitive *Gravity* were known, it would not only determine the Figure of the Earth, but demonstrate its Motion round its Axis.

ON

ON the other hand, if we take the Motion of the Earth for granted, as I believe there is at present no Philosopher that calls it in question ; and if its Figure is otherwise known, the different Gravitations will discover the quantity of primitive Gravity in the respective Places.

HENCE likewise it may be discovered whether, notwithstanding the differences observed in Gravitation, the primitive Gravity be every where the same and tends to a Centre, as Mr. *Huygens* supposed ; or if it is different in different Places, and depends upon the mutual Attraction of the parts of Matter, according to Sir *Isaac Newton* ; whether it varies according to any other Law, and to what points it tends. In fine, the Knowledge of Gravitation towards the Earth, may open the way to that of universal Gravity, the principal Agent in the Machine of the Universe.

C H A P. II.

*Experiments made at Pello, upon the
Gravitation of Bodies.*

I.

WE had resolved to make our Experiments upon Gravitation as near the Pole as possible; and for that purpose chose *Pello*, whose Latitude is $66^{\circ} 48'$.

THESE Experiments, which elsewhere would be easy enough, were in this Country attended with very great difficulties; and without an extraordinary care to master them, one should find himself very much out in his Reckoning. The great number of Experiments we made, and the great number of Instruments we used, have taught us what close Attention must be had to the smallest Circumstance: and if ever any after us shall undertake such Experiments, and in such a Country, they will be sensible how necessary all our Caution was, and how pertinent

continent the Account is that I am now to give.

'T WAS these same Difficulties that hindered Mr. *de la Croyere* to make his Experiments at *Kola* and at *Kilduin*, and forced him to give up the Advantages of this Country, for the Convenience of making them at *Archangel*, farther from the Pole. For us, we were so many, and so well assisted, that we were able to get over a great many Obstacles, and to pursue our Resolution of examining the Gravitation of Bodies in the frigid Zone.

AND it is the singular Advantage of these Experiments, that they were made nearer the Pole than any ever were, without having at all suffered in point of Accuracy, either from the Rigor of the Climate, or any other of the Difficulties we had to struggle with.

II.

THE Instrument which we used for discovering the difference of Gravitation at *Pello* and at *Paris*, is a Clock of a particular Construction, invented by Mr. *Graham*, on purpose for such Experiments.

P

THE

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THE Pendulum is composed of a heavy Bob, of the ordinary Lenticular Form, fitted to a flat Brass Rod. This Rod is terminated a-top by a piece of Steel perpendicular to it, whose Extremities are formed into two Edges, that, instead of going between two inclined Planes or two Cylinders, rest upon two flat pieces of Steel, lying both in the same horizontal Plane. The Situation of this Plane is just, when the Extremity of the Rod answers to the Point *o* of a Limb, in whose Plane the Pendulum moves, and which measures the Arcs described.

THE whole Instrument is inclosed in a very strong Case; and when it is removed, the Pendulum is screwed up by means of a Frame, so as the Steel Edges do not bear on any thing; while the piece of Steel whereof they are formed, is supported on either side of them.

WITHIN the Box, there is applied a piece of Wood hollowed, to receive the Bob of the Pendulum, and so secured by another piece that shuts over it, that neither the Lens nor the Rod can receive any motion. The only

only liberty the Rod has, is to lengthen and contract itself as the Heat or Cold requires; in this respect nothing confines it.

THE Lens is 6 inches $10\frac{3}{4}$ lin. in diameter, and its thickness at the Centre 2 inches $2\frac{3}{4}$ lin. The Weight that gives motion to the Clock is 11 lb. $14\frac{1}{2}$ Ounces, and is wound up once in a Month. And last of all, there is fix'd within the Box a Mercurial Thermometer, in which the Point of boiling Water is marked 0, and the Numbers of the Divisions increase with the Cold. Mr. *Graham* sent us, with this Instrument, an Account of the Experiments he had made with it at *London*; wherein he tells us, that when the Thermometer was at 138, the Clock gained upon the *Mean Time* 4' 4" in a Day; that when it was at 127, it gained 3' 58". And thus a difference of 11 Divisions in the Thermometer produced the difference of 6" in the Motion of the Clock.

WITH the ordinary Weight, it described Arcs of $4^{\circ} 20'$; with half that Weight it described Arcs of $3^{\circ} 0'$; and these great Differences in the Weight and Arcs produced in the going of the Clock,

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only a Difference of $3\frac{1}{2}$ " or 4" in a day. But so much faster did the Clock go when the smaller Arcs were described.

ONE may see from this how little this Clock will be affected by small Differences in the Weights or Arcs, and consequently by the different Tenacity of the Oil; and how far one may be assured, that its Acceleration from one Place to another is the Effect either of an Increase of Gravitation, or of the Cold shortening the Rod of the Pendulum.

III.

PELLO is a Village of *Finlanders*, as you go up the River of *Torneå*, agreeably enough situated upon its Banks. The Art of Masonry is there absolutely unknown. Our Lodgings were small Hutts built of Wood, but had nothing of that Solidity which our Experiments required, where there are wanted the very firmest Supports.

TOWARDS the end of Summer we had caused to be built in one of our Rooms, a great Pillar of hewn Stone; its Thickness 6 foot by three; in which we had fastened several pieces of Iron to support our Telescope

scopes and Clocks. To this Wall, which was by this time well dried and settled, we fixed a Telescope pointed to *Regulus*, very near his Passage in the Meridian; and having placed the Clock with all necessary Care,

REGULUS past by the Vertical Thread in the Focus.

1737.

The 3d of *April* at $8^h 35' 13''\frac{1}{4}$ by the
 4th . . . 8 36 14 [Clock.
 5th . . . 8 37 8

FROM these Observations, the Pendulum from the 3d to the 4th, had gained upon the Revolution of the fixt Stars $1' \frac{3}{4}''$; and from the 4th to the 5th, $54''$.

IV.

WE were sensible that this Inequality in the Clock's Motion proceeded from the different degrees of Heat and Cold; and that, though the Room was as closely shut as it was possible in this Country, yet the different Temperature of the Air would de-

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stroy all Accuracy in our Experiments. Our only resource was to keep the Clock always in the same degree of Heat. This was no easy Undertaking in the midst of a Cold so intense, and at the same time so variable; Day and Night we must have our Eyes fixed upon the Thermometers, to increase the Fire, or let in the external Air. Yet by extraordinary Patience and Attention we overcame all this; kept the Air to a constant Temperature, and made the Clock go with as equal a Motion as can be expected in the most favourable Climate. The proof of this was the Experiments themselves, in which the smallest Neglect must have showed itself.

V.

ON the 6th we began to regulate the Fire, by means of two Mercurial Thermometers, which we used all along in these Experiments, both here and at *Paris*. The one made by the Abbé *Nolet*, after Mr. *de Reaumur's* Standard; the other by Mr. *Prins*. These Thermometers are differently divided; in the Abbé *Nolet's* the freezing Point is marked 0, and in that of Mr. *Prins* it is marked 32. In either, the Numbers

bers increase with the degrees of Heat, and one of the Abbé *Nolet's* Divisions is equivalent to very near two of Mr. *Prins's*. They were placed by the Pendulum, and at the height of the middle of its Rod; and kept continually, for the five days and five nights that these Experiments lasted, the Abbé *Nolet's* between 14 and 15 degrees, and Mr. *Prins's* between 60 and 62.

IT was of great consequence that the Thermometers should be placed not only at the same distance from the Fire as the Pendulum, but likewise at the same height; for upon lowering them, though at the same distance from the Fire, the Mercury would fall considerably.

THE differences in the length of a Pendulum arising from Heat and Cold, are so considerable with respect to those which proceed from the Increase of *Gravitation*, that without this Attention to the equal Temperature of the Air, there can never be any tolerable Conclusion drawn from such Experiments.

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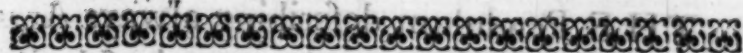
THE Pendulum describing always Arcs of $4^{\circ}.10'$. that is, $2^{\circ}.5'$. on each side of the Limb that measures them, our Observations, after we had regulated the Temperature of the Air, were as follows :

Regulus passed the Thread of the Telescope,

1737.		h	'	"
6th of April		at 8	38	1
7th	.	8	38	$54\frac{1}{4}$
8th	.	8	39	$48\frac{1}{2}$
9th	.	8	40	42
10th	.	8	41	35

FROM these Observations it appears, that from the 6th to the 10th, the Clock had gained $3'.34''$. which gives, for its Acceleration upon one Revolution of the fixt Stars, $53''.5$.

CHAP.



CHAP. III.

Observations made at Paris with the same Instrument.

AT Paris, in the same Temperature of the Air, kept up Day and Night by the same two Thermometers we had used at Pello, placed in the same manner, the Pendulum swinging Arcs of $2^{\circ} 10'$ on either side.

Sirius passed the Thread of the Telescope.

1738.					
28th of Febr ^y	.	.	.	at 8 45 40	
3d of March	.	.	.	8 45 24	
4th	.	.	.	8 45 19	
9th	.	.	.	8 44 49	
10th	.	.	.	8 44 43	
11th	.	.	.	8 44 38	
12th	.	.	.	8 44 32 $\frac{1}{2}$	
13th	.	.	.	8 44 27 $\frac{1}{2}$	

WHENCE in 13 Revolutions of the fixt Stars the Pendulum had lost $1'. 12'', 5$ which

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which gives for one Revolution a Retardation of 5,6.



C H A P. IV.

Accelerations of the Clock.

I.

Acceleration between Paris and Pello,

WE have found (*p.* 216.) that at *Pello*,
in one Revolution of the fixt Stars,
the Clock gained upon their Motion 53,5
and that at *Paris* it lost 5,6

Whence from *Paris* to *Pello* the
Acceleration is 59,1

II.

*Acceleration of the Clock between Paris and
London.*

Mr. *Graham*, upon whose Experiments
we reckon no less than upon our own, had
observed at *London*, that when the Ther-
mometer contained in the Case of the Clock
stood at 127, the Clock gained upon the
Mean

Mean Time 3', 58". in a day, that is, 2", 1
upon one Revolution of the fixt Stars.
Now this Division 127 of his Thermome-
ter answering to 14 $\frac{1}{2}$ and 61 of these two
which we used both at *Pello* and at *Paris*,
it is plain the Experiments at *London* and at
Paris were made in an Air of the same
Temperature. The Oscillations were like-
wise the same, viz. 2°. 10". on either side
of the Perpendicular. Whence the Clock
having, at *London*, gain'd upon one Revolu-
tion of the fixt Stars 2", 1
and at *Paris* having lost 5, 6
the Acceleration from *Paris* to *London*
in one Revolution, is 7, 7



CHAP. V.

Experiments made with other Instru- ments.

WE had another Instrument, excel-
lent for these Purposes; a Clock of
Mr. *Julian le Roy*, which, in all the Trials
we made, was found to go admirably well.

ALL

ALL this Country being, as it were, one Mass of Iron and Loadstone, we apprehended the effects of some Magnetism in using this Clock, whose Rod was of Steel. We likewise wanted to make some Experiments with Pendulums of different specific Gravities. Mr. *Camus*, who joins to his other Accomplishments a perfect Skill in Mechanics, supplied alone whatever we could want in a Country that knows no other Arts but Fishing and Hunting. He formed upon a Turn, five perfect Globes of two Inches $4\frac{1}{4}$ lin. diameter, of as many different Metals which he had melted down. Each Globe was past through with a Brass Rod, which was easily fixt to the extremity of another of the same Metal; this last having been first fitted to the Clock.

IT was in the time of our most accurate Experiments at *Pello*, the 6, 7, 8, 9 and 10th of *April*, when the Air was kept Night and Day in the same degree of Heat, that we made the Comparison of the two Clocks, Mr. *Graham's* and Mr. *le Roy's*. We made this last go 12 Hours with each of the five Globes, charging the Weight that gives the Motion

Motion with as many leaden Bullets as made the Vibrations always of $3^{\circ} 55'$ on each side. A Circumstance which we likewise observed at *Paris*.

THE Motion of this Clock, with the five different Globes, at *Pello* and at *Paris*, and in the same degree of Heat, was as follows :

In 12 Hours, by Mr. Graham's Clock.

	At <i>Pello</i> .	At <i>Paris</i> .
The Globe of Lead lost . .	9 14 $\frac{2}{3}$	9 14
The Globe of Silver lost . .	8 42	8 44
The Globe of Iron lost . .	5 29	5 29 $\frac{1}{2}$
The Globe of Tin lost . .	6 6	6 8
The Globe of Copper lost . .	6 48	6 50

THE difference of 2" which three of these Globes give between the Motion of the Clock at *Pello* and here, is not considerable. It may probably have been occasioned by the manner in which the Rods of the Globes were fitted to the Clock. If the extremities of the Rods to which the Globes were fixed, miss'd ever so little to rise to the same point of the Rod that was common

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mon to them all, some small difference in the lengths must happen. And how small indeed is sufficient to produce a difference of 2" ! This, however, must always be a Source of some little Error in Experiments made with Clocks, whose Pendulums are taken off, when they are carried from one place to another.

HENCE we may see how proper good Clocks are for discovering the Increase or Decrease of Gravitation. And if it had not been actually verified, no body could ever have believed, that in these Experiments two Clocks of such different Construction as Mr. *Graham's* and Mr. *le Roy's* are, should so accurately correspond. In Mr. *le Roy's*, the Rod of the Pendulum was fixt to two Springs, which might be suspected to have different Elasticities : The Globes differed widely from Mr. *Graham's* Lens, in Weight as well as Shape ; and the Arc which they described was almost double to that of the Lens.

WE shall say nothing of some other Experiments which give the Increase of Gravitation at *Pello* still greater than we found

found it by Mr. *Graham* and Mr. *le Roy's* Clocks, because the Instruments with which they were made, are so inferior to these Clocks that they ought not to be so much as compared with them.



CHAP. VI.

Reflections upon the Increase of Gravitation.

I.

Comparison of the Increase of Gravitation between Paris and Pello, with the same as deduced from Sir Isaac Newton's Table.

THE Acceleration from *Paris* to *Pello*, found as above, is greater by 6", 8 than Sir *Isaac Newton's* Table makes it, (*lib. 3. Phil. Nat. Princ. Math.*) and consequently, according to his Theory, the Earth is flatter than he determines it to be.

II. Com-

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II.

Comparison of the Increase of Gravitation between Paris and Pello, with what results from the Experiments made at Jamaica.

FROM Mr. Campbell's Experiments at Jamaica made with one of Mr. Graham's Clocks, Mr. Bradley has calculated another Table, (*Phil. Trans.* N°. 432.), upon the Principle employed by Sir Isaac Newton and Mr. Huygens, that Gravitation increases towards the Pole as the Square of the Sine of the Latitude; and the Acceleration from Paris to Pello, as deduced from this Table, exceeds what we found it to be, by 4", 5.

III.

Comparison of the Increase of Gravitation with what results from Mr. Huygens's Theory.

IN fine, All the Experiments which the Academicians, sent by the KING to Peru, have made, either at *S. Domingo* or the *Equator*, conspire with ours, to make the Increase of Gravitation towards the Pole, greater than according to Sir Isaac Newton's

Newton's Table, and by consequence the Earth flatter than he has made it. And all of them fall so wide of Mr. Huygens's Theory (*Discours de la cause de la Pesanteur*) which makes it still less, that his Theory must itself be wide of the Truth.

IV.

Comparison of the Increase of Gravitation between Paris and Pello, with that between Paris and London.

THE Acceleration from *Paris* to *Pello* being 59", 1. that from *Paris* to *London* ought to be 9", 8. and we found it above, to be 7", 7. Whether this difference is real, or if it is owing to some Error in our Experiments, I leave others to judge. And if this last is the case, how exquisite must that Instrument be, which, transported from *London* to *Pello*, from *Pello* to *Paris*, and tried in these three places, is found to agree so accurately with itself?

Q

V. Com.

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V.

Comparison of the Gravitation of Bodies at Paris to that at Pello.

THE Gravitation of Bodies at *Paris* is to that at *Pello*, as the Square of the Number of Oscillations of a Pendulum at *Paris* in one Revolution of the fixt Stars, is to the Square of the Number of Oscillations at *Pello* in the same time, that is, as 10000 to 10014.

VI.

Length of the Pendulum that swings Seconds at Pello.

TO find the Length of a Pendulum that swings Seconds at *Pello*, you have only to compare the Squares of the Number of Oscillations made in the same time at *Pello*, and at *Paris*, with the length of a Pendulum at *Pello*, and that of a Pendulum at *Paris*; which last Mr. *de Mairan*, has, by repeated and unquestionable Experiments, found to be 440,57 Lines. And you will find the length of a Second-Pendulum at *Pello* to be 441,17 Lines.

FOL-

FOLLOWS a *Table*, which I have calculated, upon the Increase of Gravitation between *Paris* and *Pello* as above determined; and upon this Principle, That Gravitation increases from the Equator to the Pole, very nearly in the Ratio of the Squares of the Sines of Latitude. In this Table, the Augments of Gravitation are expressed two different ways; by the *Accelerations* of a Clock in a Revolution of the fixt Stars, and by the *Lengthenings* of a Pendulum that swings Seconds from the Equator to the Pole.



Q 2

TA-

TABLE

Of the Accelerations of a Clock, and of
the Lengthenings of a PENDULUM
from the Equator to the Pole.

LATITUDE of the Place.	ACCELERATION in one Revolution of the fixt Stars.	FRACTIONS of a Line, and Lines by which the Pendulum is to be lengthened.
0°	0"	0
5	1,6	0,016
10	6,4	0,065
15	14,3	0,145
20	24,9	0,254
25	38,1	0,387
30	53,3	0,542
35	70,2	0,713
40	88,1	0,896
45	106,6	1,084
50	125,1	1,273
55	143,1	1,455
60	159,9	1,626
65	175,1	1,781
70	188,3	1,915
75	198,9	2,023
80	206,8	2,103
85	211,6	2,152
90	213,2	2,169



C H A P. VII.

A Method for finding the Direction of Gravity.

P R O B L E M.

The Figure of the Earth being given, as also the Proportion of Gravitation at the Equator to that of any given Latitude; To find the Angle which the Direction of the actual Gravitation makes with the Direction of the primitive Gravity, or that Point of the Earth's Axis to which Gravity tends.

LET the Spheroid $APap$ represent Fig. 18. the Earth, whose Axis is Pp , and the Diameter of the Equator Aa . Let the Gravity in A , that is, at the Equator, be represented by AG ; and the centrifugal Force by AQ ; then will the Gravitation there be represented by AH , the difference of AG and GH (or of AG and AQ)

IN

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IN any other place of the Earth D , let the Gravitation be express'd by DT . And by the Laws of Hydrostatics, seeing the Direction of Gravitation is always perpendicular to the Surface of the Earth, DT will be perpendicular to a Line touching the Spheroid in D .

IF upon FD continued, there be taken $DZ = \frac{DF \times A^2}{AC}$, DZ will represent the centrifugal Force in D , and its Direction will be that of DZ .

DRAWING then from the Point T , the Lines TN , TS perpendicular to the Axis, and forming the Rectangle $DNTS$, the Gravitation will be resolved into two Forces, one acting in the Direction DS , which is not affected by the centrifugal Force; and the other acting in the Direction DF , which has been diminished by it.

THE centrifugal Force has taken from this last the Quantity $DZ = \frac{DF \times A^2}{AC}$,
which

which must be restored to the Force in the Direction DF , in order to find the whole Force of primitive Gravitation in the Direction DF . Taking therefore $NV = DZ$, and, through V , drawing VO parallel to the Axis, the Lines VO , SO will represent the Forces which result from Gravity. The Diagonal DO , the quantity of Gravity itself, and the little Angle ODT will be that of the two Directions of Gravity and Gravitation.

THE centrifugal Force at the Equator being $\frac{1}{288}$ of the Gravitation, we have $AQ = \frac{1}{288} AH$, and $DZ = \frac{DF \times AH}{288 AC}$

TO . Having drawn from a Point infinitely near D , the Line dM parallel to DE , and from the Point T , the Line Tt perpendicular to DO , we shall have by similar Triangles $Dd : Md :: TO : Tt$, or

$$Dd : Md :: \frac{DF \times AH}{288 AC} : Tt =$$

$\frac{Md \times DF \times AH}{288 \times Dd \times AC}$, the Sine of the Angle

TDO to the Radius DT . Whence we have

the Equation $\frac{Tt}{Dt} = \frac{Md \times DF \times AH}{288 \times Dd \times AC \times DT}$

THIS

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THIS Formula contains the Angle of the two Directions of Gravity and Gravitation ; the Latitude of the Place express'd by $\frac{M d}{D d}$; the Radius of the Equator, and the Radius of the Parallel under which the Experiments are made ; with the Ratio of Gravitation at that Place to Gravitation at the Equator. Whence different Theorems may be deduced, for different Suppositions of the known Quantities.

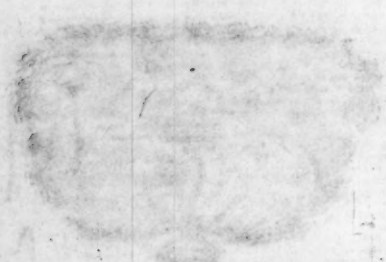
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The First of Geometrical Books

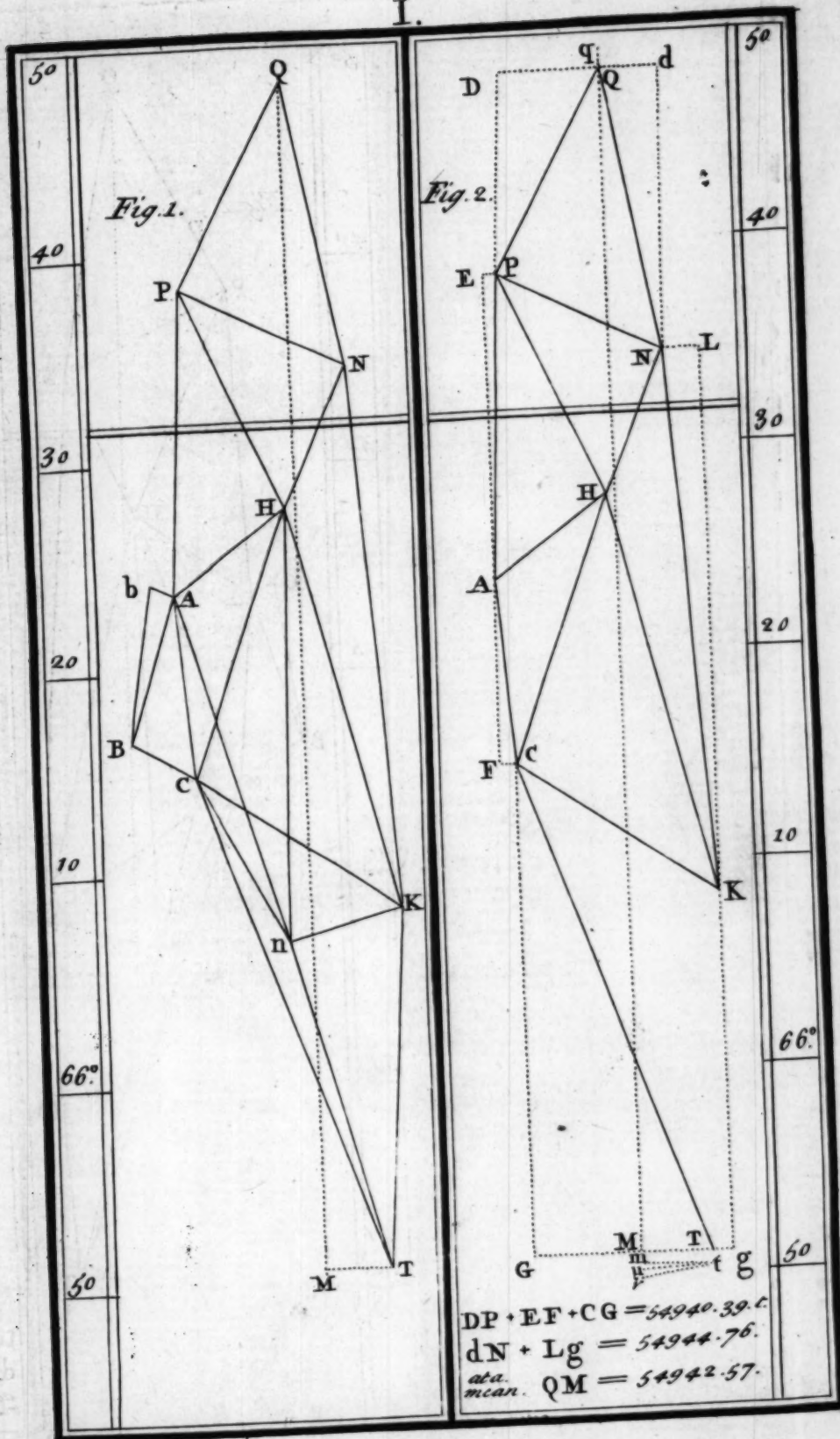
THIS Figure contains the Angle
 in two Dimensions of Gravity and Gravity
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 $\frac{M}{D}$ the Radius of the Earth
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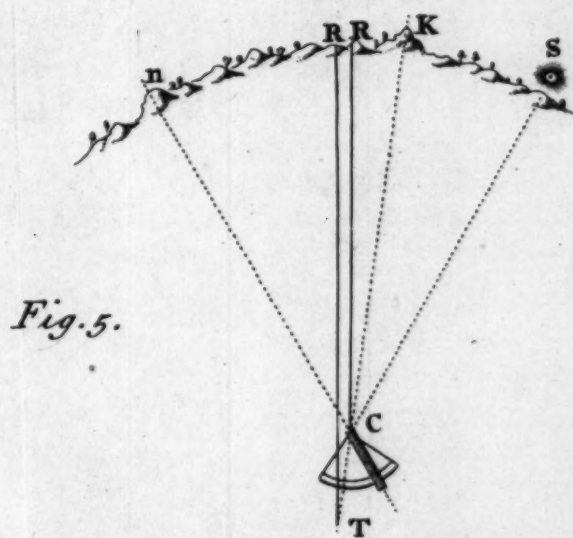
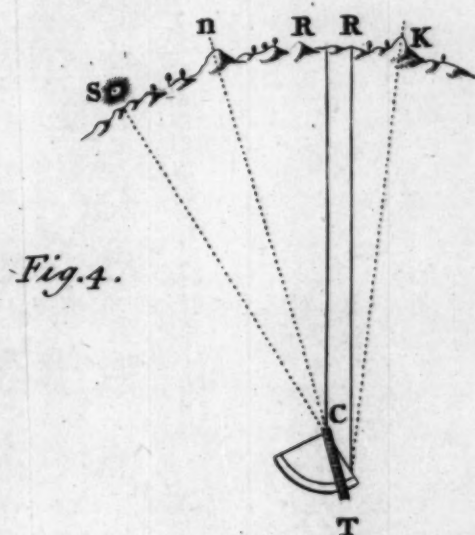
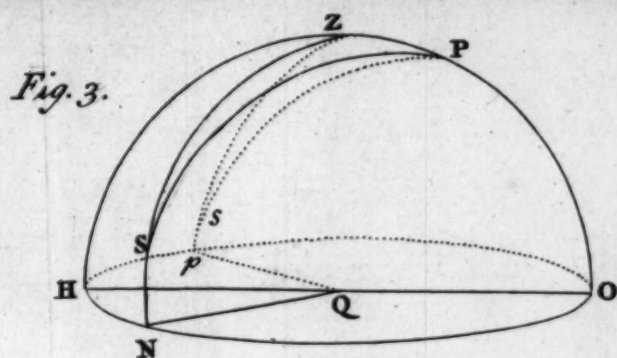
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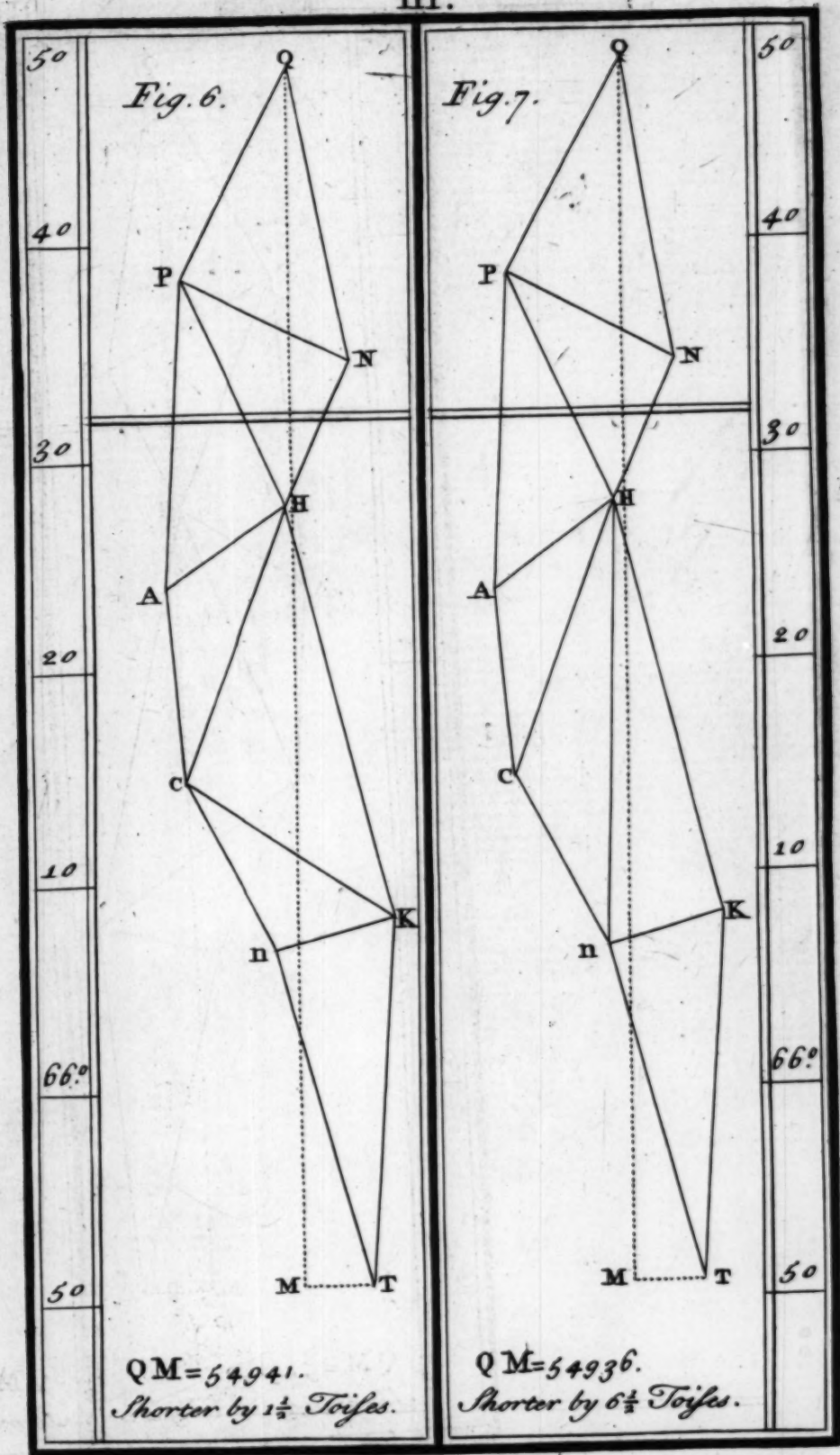
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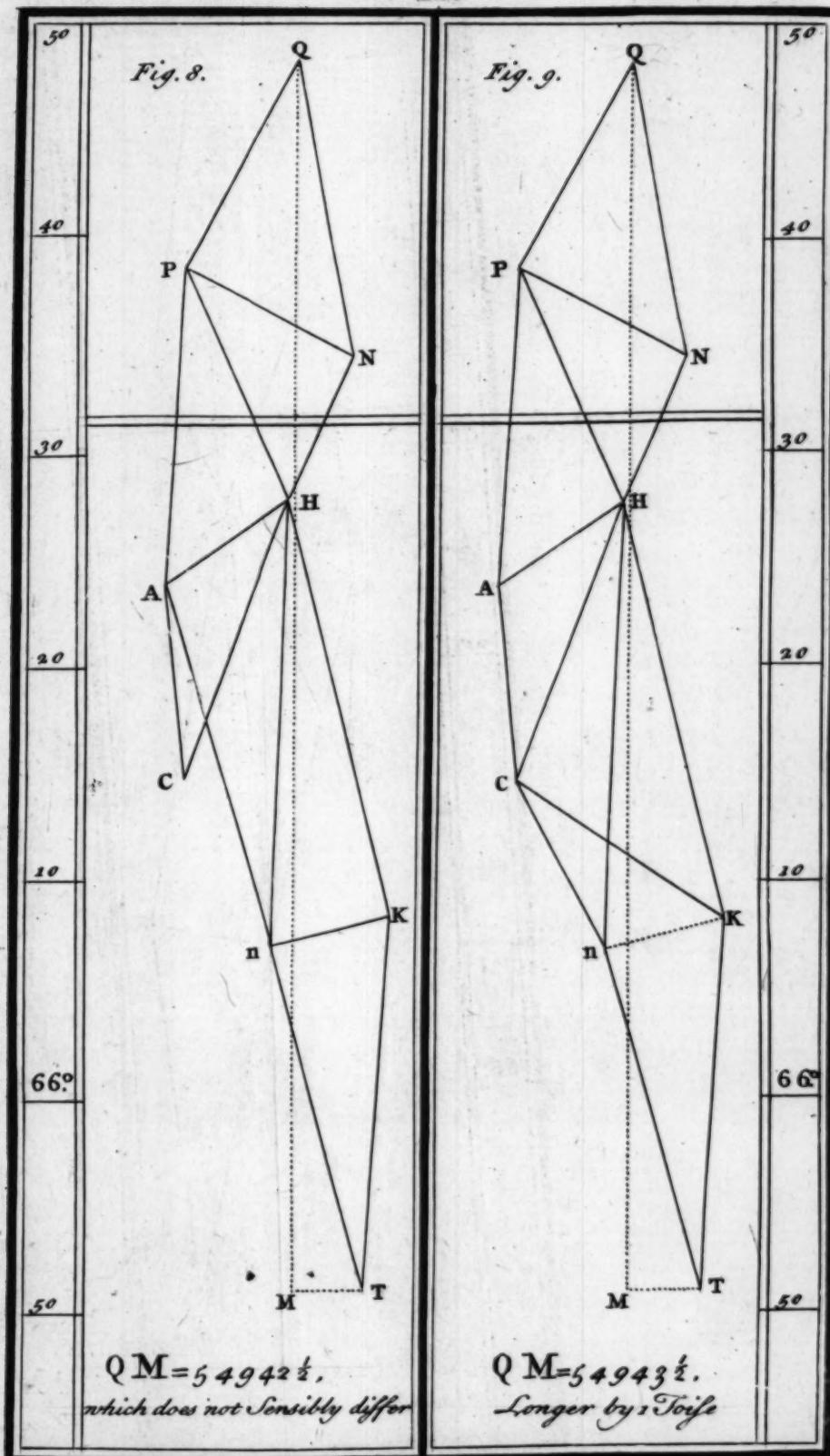
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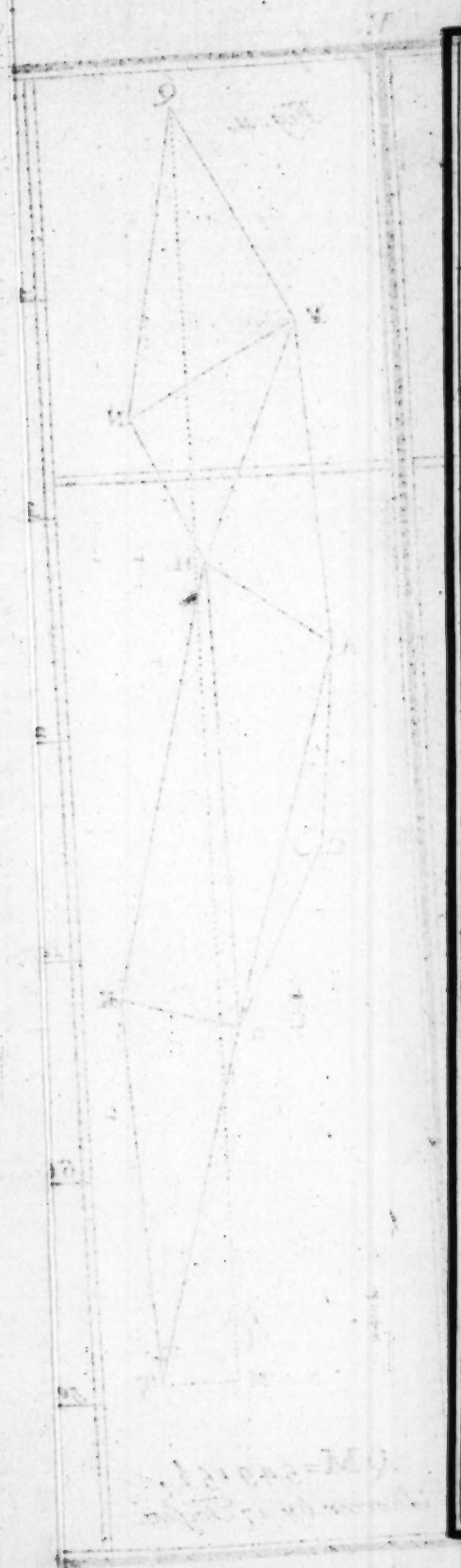
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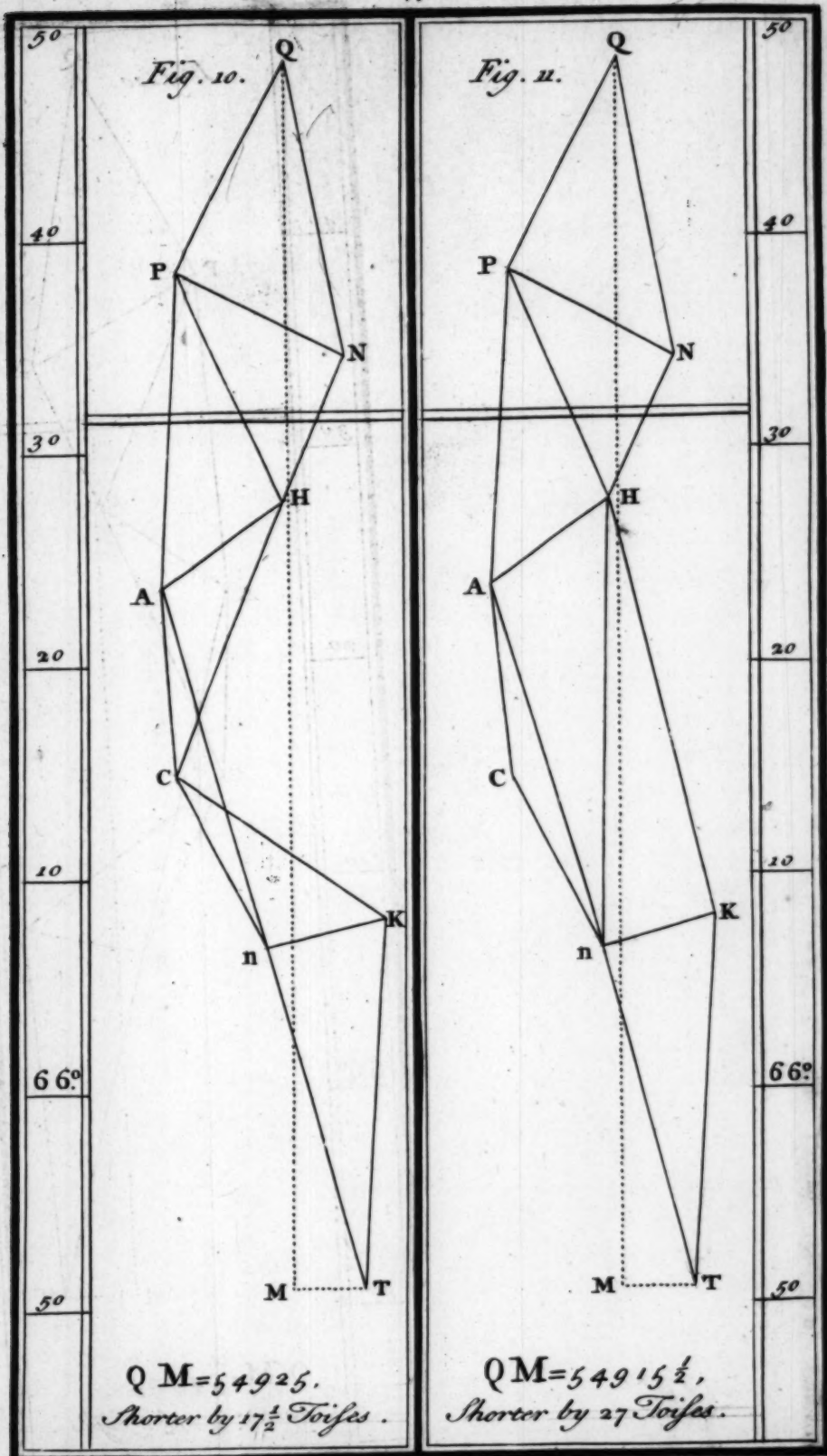


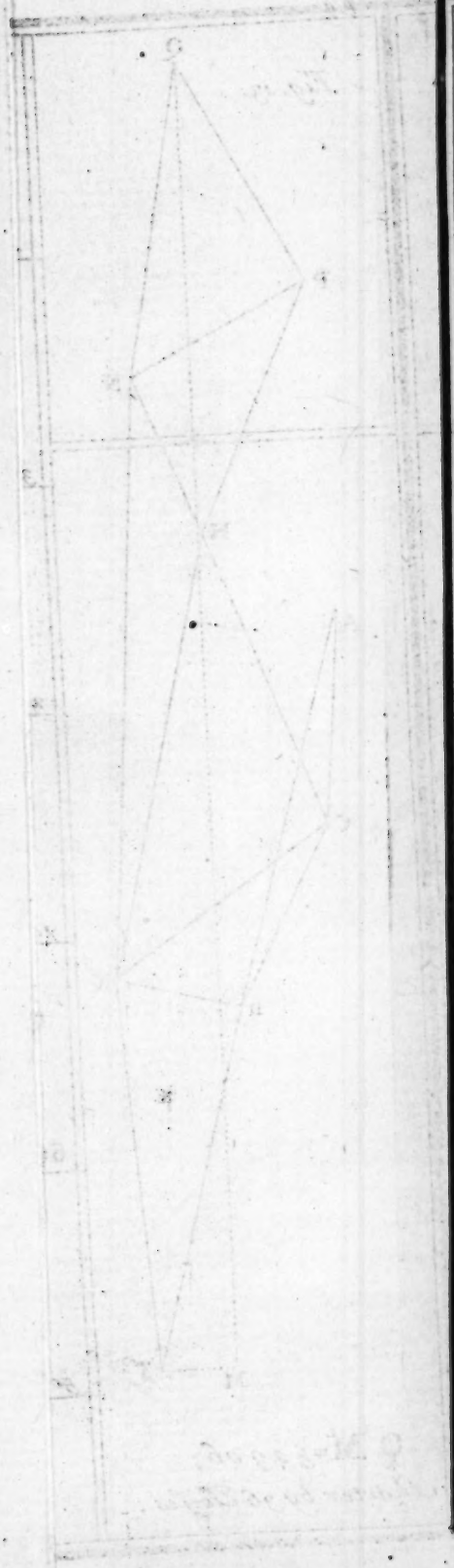
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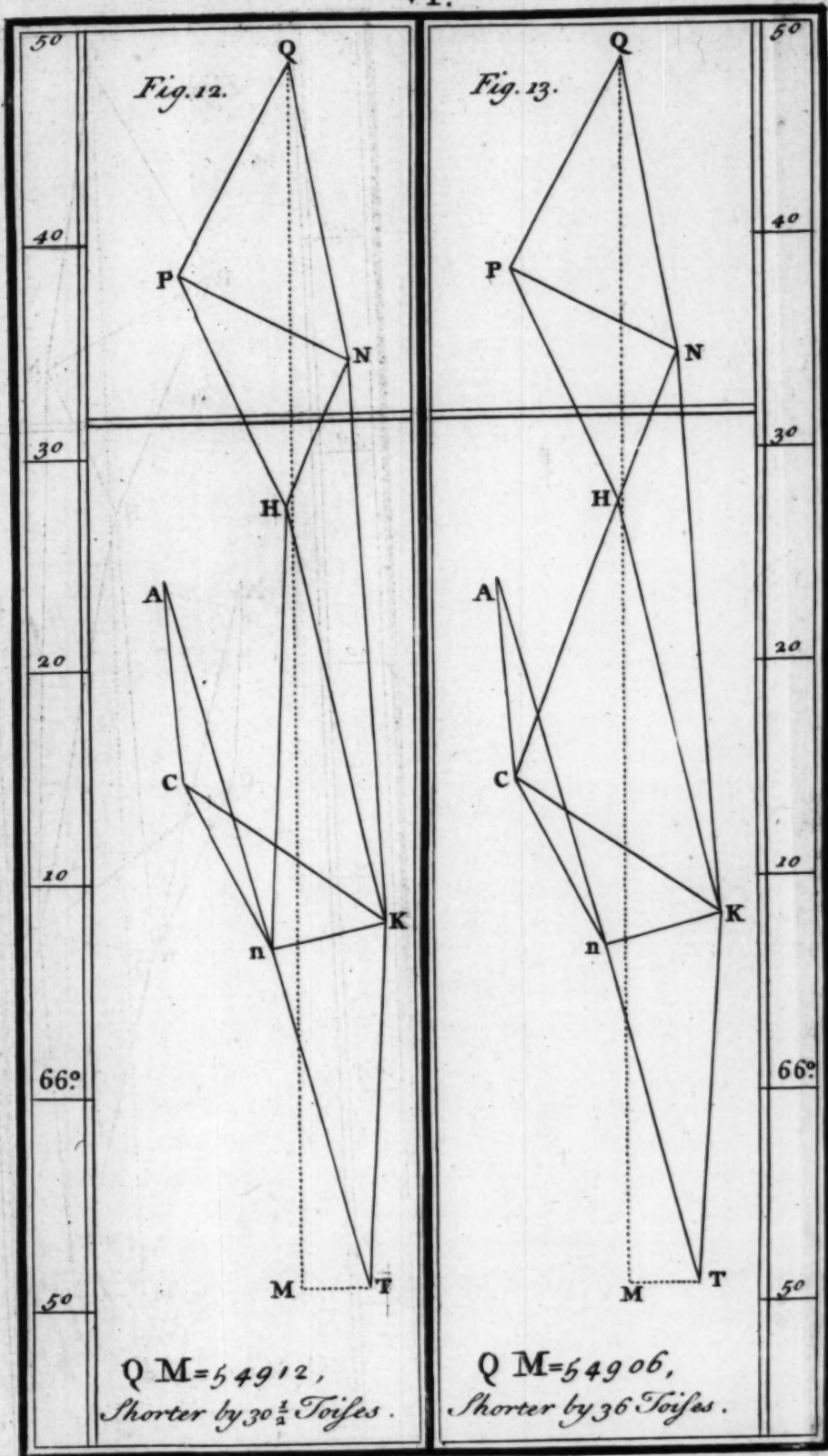


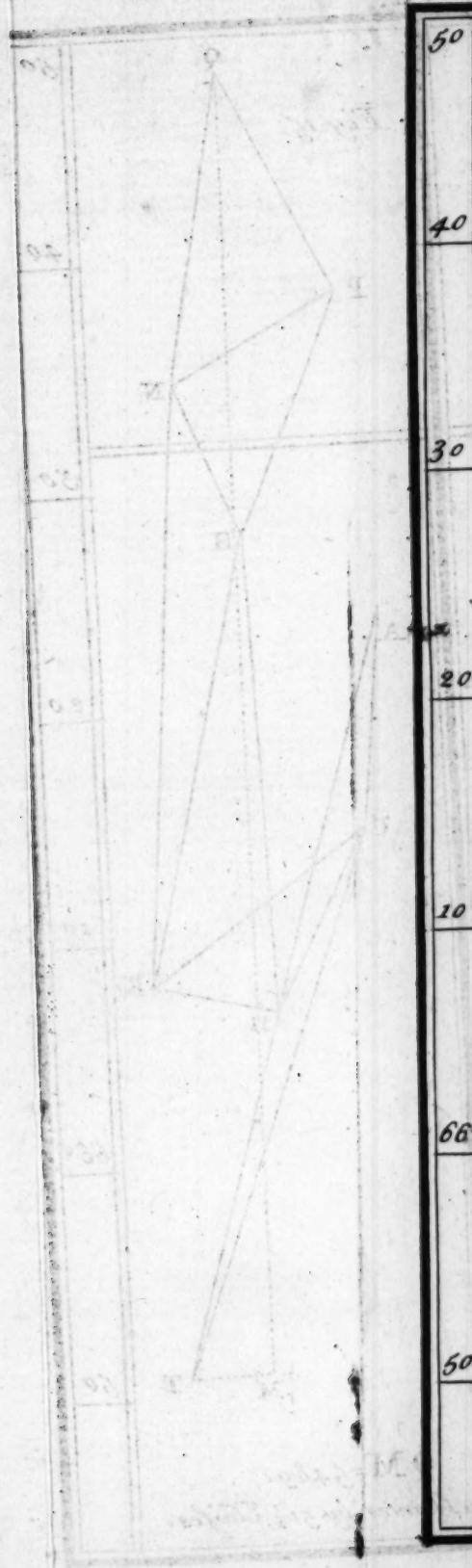






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VII.

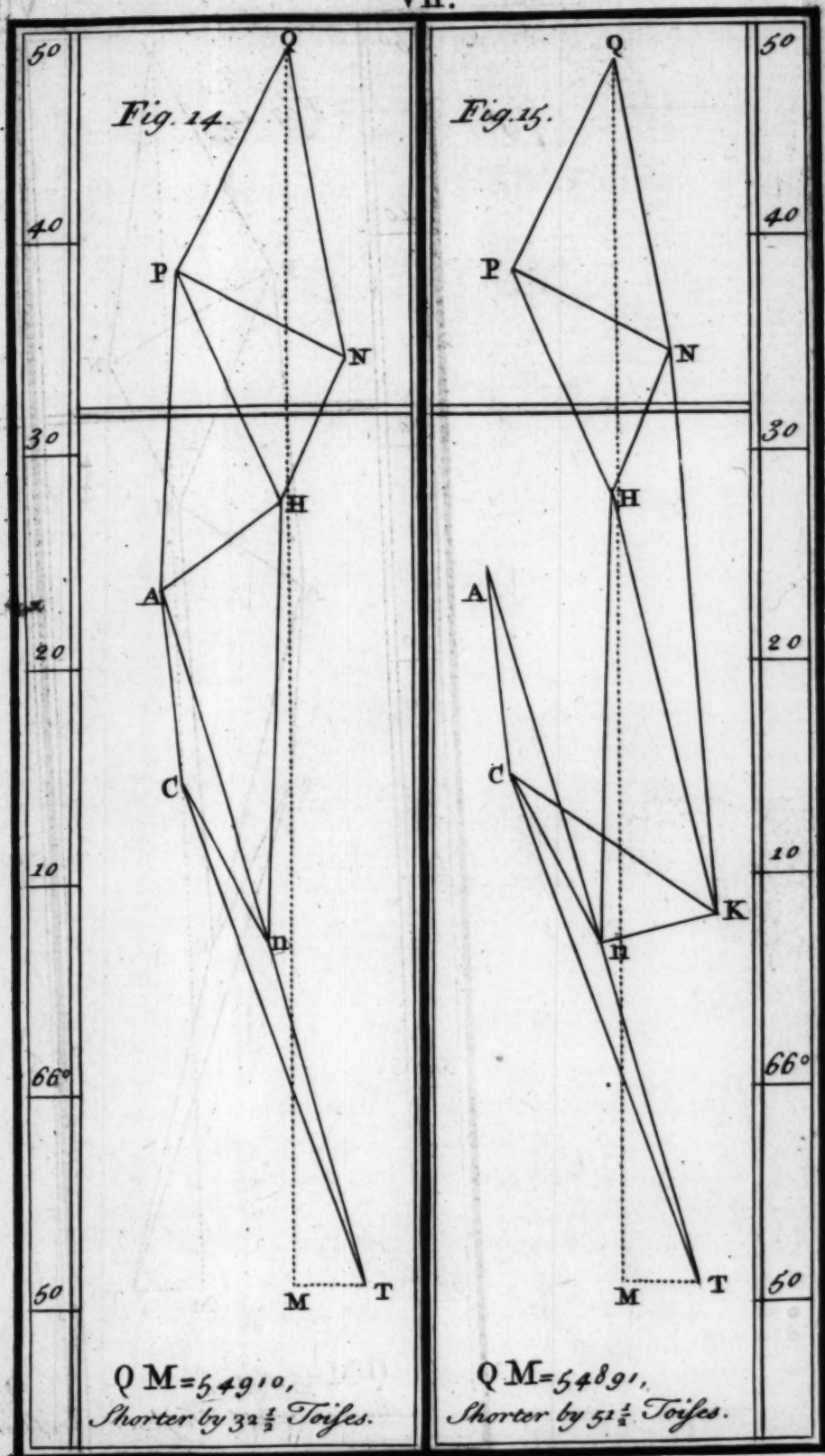
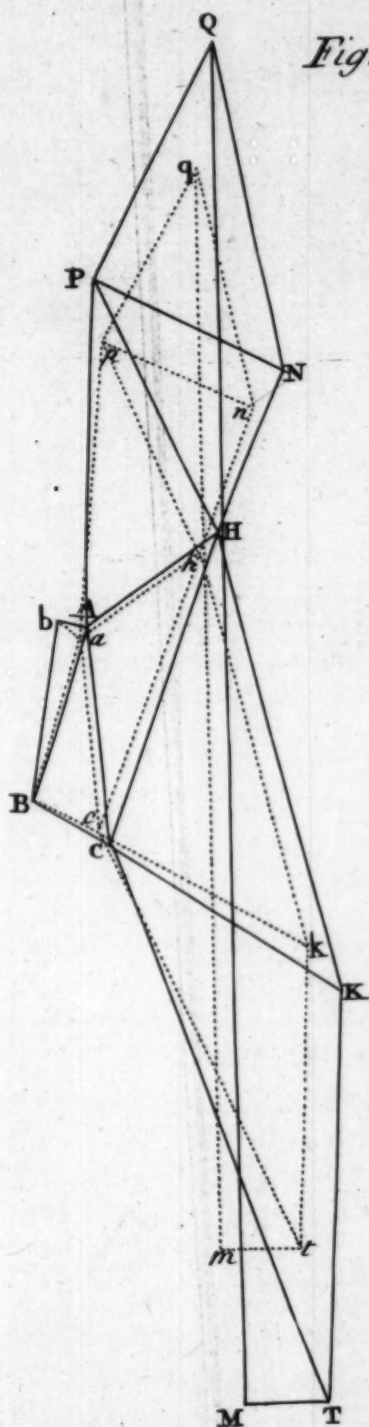


Fig. 10.



From the top of the tower.

Fig. 16.



$qm = 54886$ Toises, Shorter than QM by 54 Toises.



IX.

